SEGIS Technology Demonstration: Solutions for High Penetration Solar PV

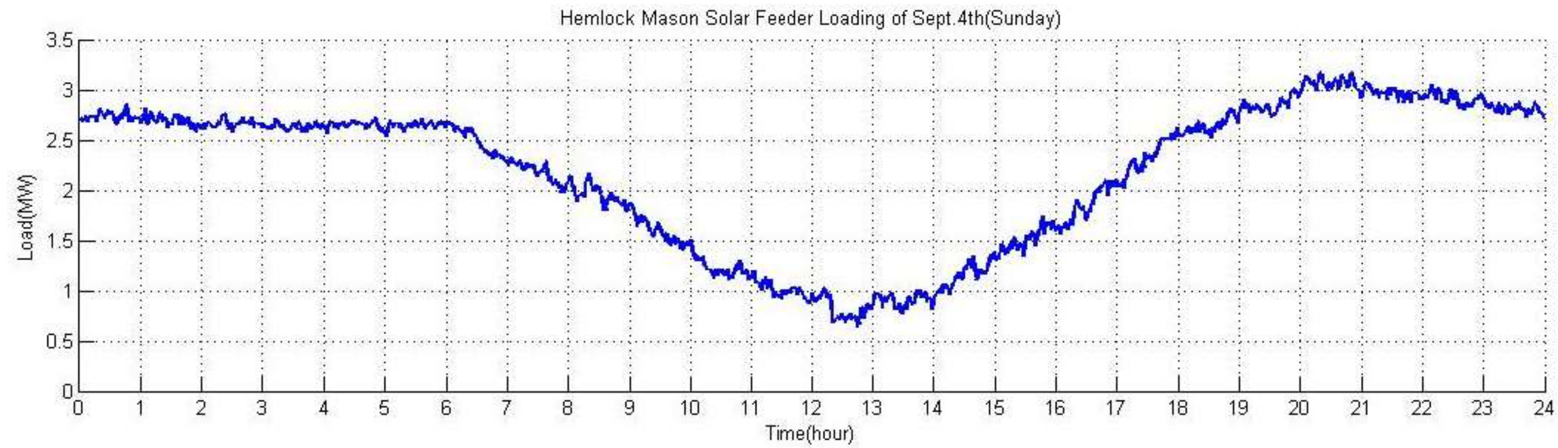
Gregg Patterson
President
AE Solar Energy

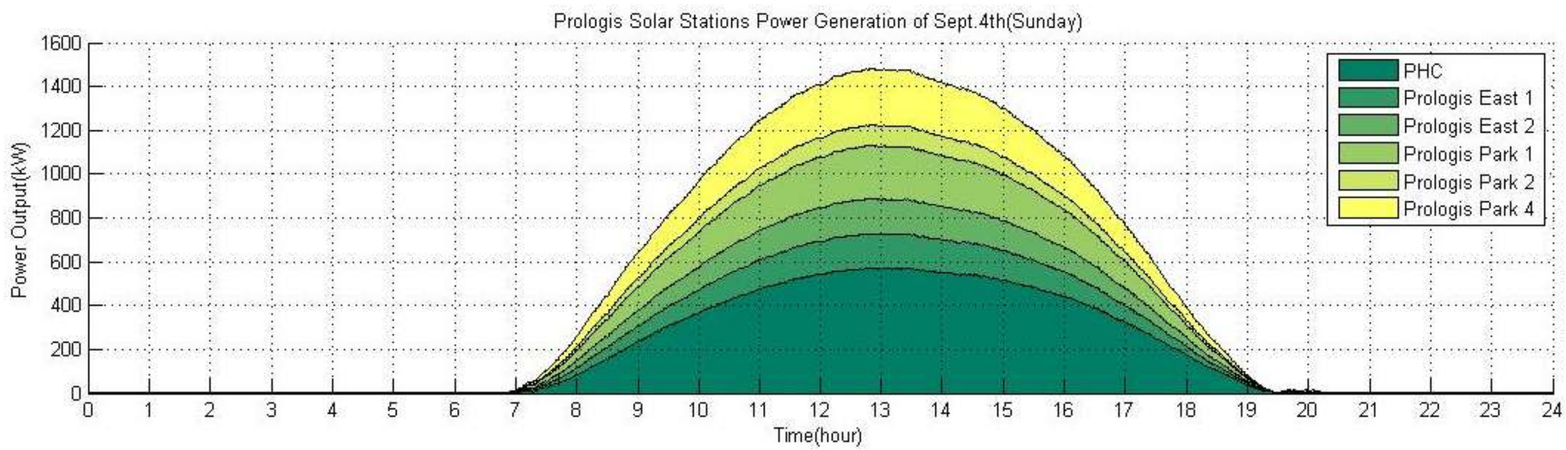
September, 20, 2011

MICHAEL MILLS-PRICE, PE
SEGIS PROGRAM MANAGER

Introductions

Solar Energy Grid Integration System Technology Developments





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Keynote and Partner Introductions

- **8:05 – 8:30: Event Keynotes**
  - Kevin Lynn, Lead for Systems Integration, U.S. Department of Energy
  - Ward Bower, Distinguished Members of the Technical Staff, Sandia National Laboratories
  - Steve Hummel, VP of Engineering, AE Solar Energy

- **8:30 – 8:50:SEGIS Partner Introductions**
  - Mark Osborn, Distributed Resource Manager, Portland General Electric
  - Dave Whitehead, VP of Engineering, Schweitzer Engineering Laboratories
  - Michael Ropp, Principal Engineer, Northern Plains Power Technologies

- **8:50-9:00: Opening Comments Wrap Up and Q&A**
  - Steve Hummel, VP Engineering, AE Solar Energy

Agenda: Morning Presentations

- **9:00-10:00: Utility Interactive Controls**
  - Michael Mills-Price, SEGIS Program Manager, AE Solar Energy
- **10:00-10:15: Break**
- **10:15-11:15: Maximum Power Point Tracking (MPPT): The other half of the energy harvest equation**
  - Michael Ropp, Principal Engineer, Northern Plains Power Technologies
  - Steve Hummel, VP of Engineering, AE Solar Energy
- **11:15-12:15: Synchrophasor-based Island Detection: Solving a critical gap in utility integration under high penetration PV**
  - Mesa Scharf, Director of Solutions Engineering, AE Solar Energy
  - Michael Ropp, Principal Engineer, Northern Plains Power Technologies
  - Michael Mills-Price, SEGIS Program Manager, AE Solar Energy
- **12:15-1:15: Lunch**

Agenda: Afternoon Interactive Discussion and Live Demonstration: 2 Tracks

Red Track

1:15-3:00: Interactive Discussion at Embassy Suites

3:00-3:15: Break

3:15: Load bus to Demonstration Site

3:30: Bus departs hotel

3:45: Arrive at Prologis Demo Site

3:45 – 4:45: Live demonstration presentation

4:45: Load bus back to hotel

5:00: Arrive back at hotel

5:00 – 5:30: Conference Wrap and Refreshments

Blue Track

1:15: Load bus for Demonstration Site

1:30: Bus departs hotel

1:45: Arrive at Prologis Demo Site

1:45- 2:45: Live demonstration presentation

2:45: Load bus back to hotel

3:00: Arrive back at hotel

3:00-3:15: Break

3:15-5:00 Interactive Discussion at Embassy Suites

5:00 – 5:30: Conference Wrap and Refreshments

6:30 – 9: VIP EVENT: Buses ready to board at 6:15

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Agenda: Afternoon Interactive Discussion and Live Demonstration

Interactive Discussion

High Penetration PV Issues and Options on the Distribution Network
Tucker Ruberti, Director of Commercial Product Management, AE Solar Energy (35 min)

Utility Interactive Controls – Theory and Practice– UIC implemented PG&E/CEI
Todd Miklos, Sr. Director, Utility Inverter Marketing, MSEE

(35 min)

Q&A: 20 min

Live Demonstration

Safety Brief (5 min)

System Overview (5 min)

Tour the trailer and inverter area, electrical room (10 min)

Demonstration explanation (10 min)

Island (5 min)

3 island detection tests (15 min)

Q&A (10 min)

EVENT KEYNOTES

Keynote

Kevin Lynn
Lead for Systems Integration
U.S. Department of Energy

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September, 20, 2011

SEGIS GOALS AND ADVANCED FUNCTIONALITIES

Ward Bower; DMTS and SEGIS Project Manager
Sandia National Laboratories

wibower@sandia.gov
505-844-5206

Presented at the SEGIS Advanced Energy – PV Powered Demonstration Conference
September 20, 2011; Portland, OR

References:
http://www1.eere.energy.gov/solar/systems_integration_program.html
http://www.sandia.gov/solar/

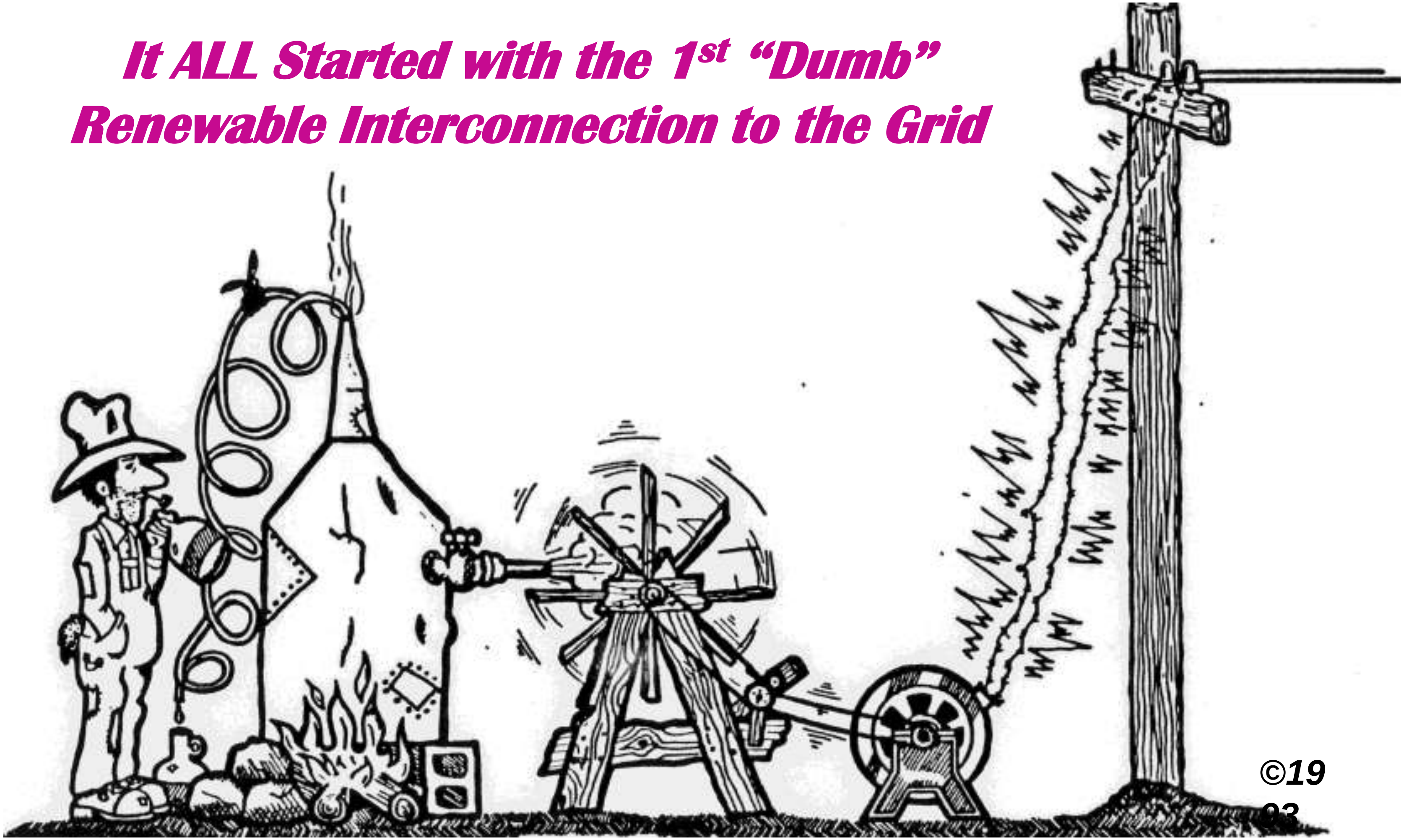
Acknowledgements
SNL SEGIS Key Program Team Members

	Project Technical Specialty
Ward Bower	Project Lead and White Paper
Chris Cameron	White Paper and Economic Analysis
Sig Gonzalez	DETL Power Hardware Validations
Scott Kuszmaul	System Communications/Logistics
Abbas Akhil	Energy Storage and Micro-grid
Lisa Sena-Henderson	Web Sites, Webinars and Graphics
Carolyn David	Contracts and Legal Communications

Specialties are listed but all participated in program logistics that included the Request for Information, Request for Proposal, Selection Criteria, Proposal Reviews, Selection Committee, Critical Design Reviews, and many other logics, monitoring, etc.

In the Beginning!

It ALL Started with the 1st "Dumb" Renewable Interconnection to the Grid



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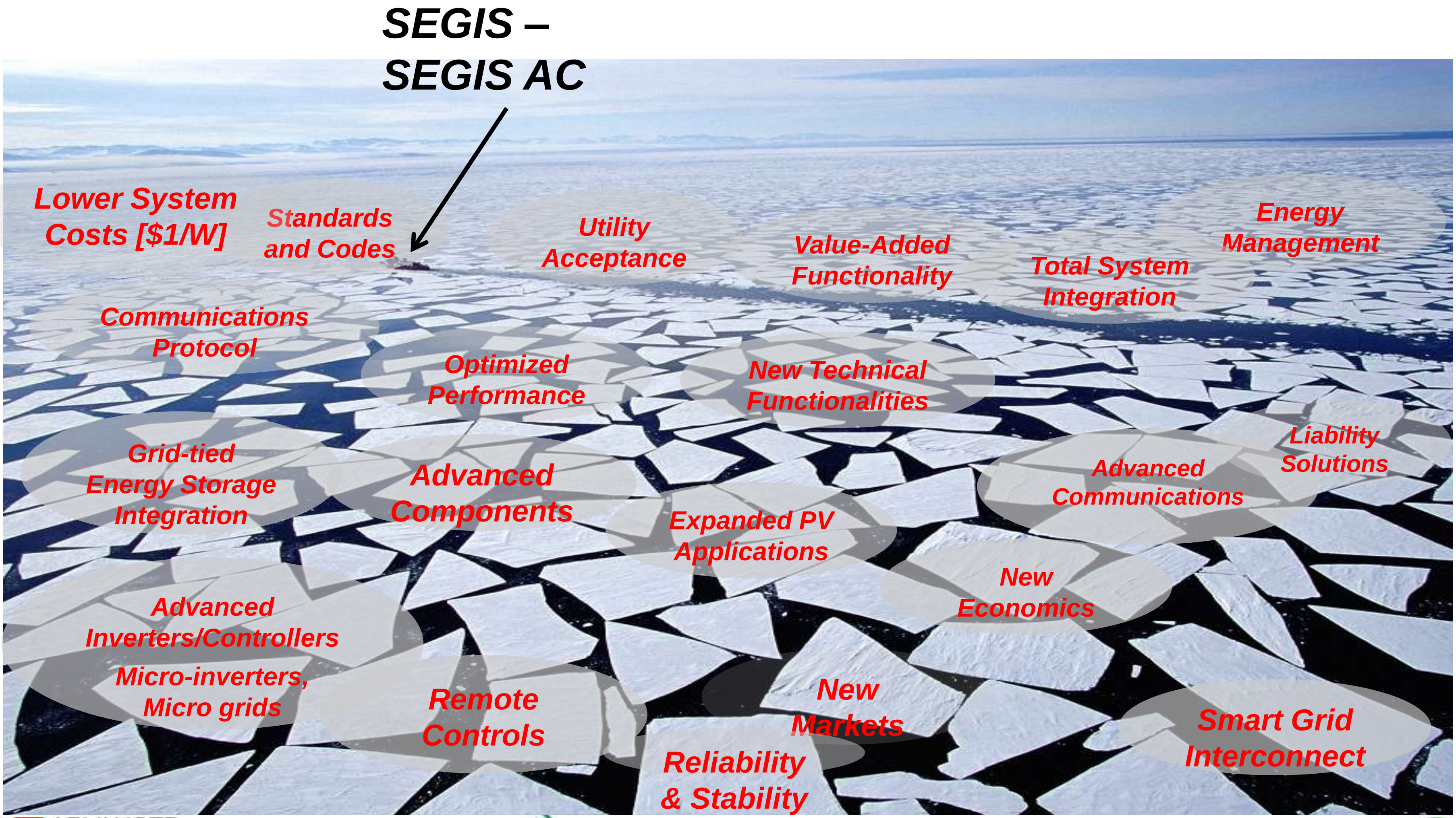
SEGIS is the First SETP Step Toward Intelligent PV Grid Integration

“SEGIS”-The 1ST SETP “Integrated PV Systems Development for Intelligent PV Interconnect”



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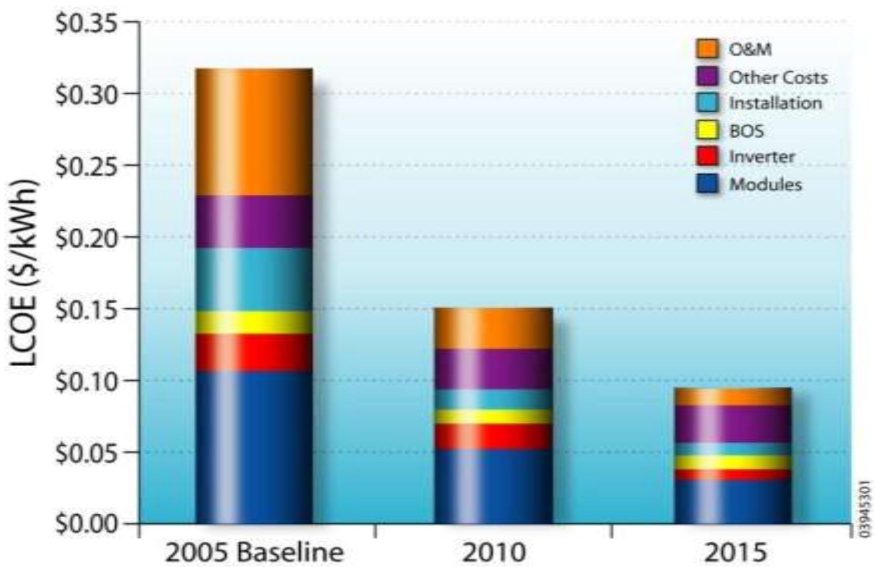
SEGIS Vision and Needs

SEGIS VISION

ENABLE HIGHLY INTEGRATED, INNOVATIVE, ADVANCED INVERTERS, CONTROLLERS, CRITICAL BOS CONCEPTS & ENERGY MANAGEMENT FOR RESIDENTIAL AND COMMERCIAL PV APPLICATIONS

All NON-MODULE costs must be reduced.



Without dramatic <u>non-module</u> cost improvements, the goals ($.05-$.10/kWh by 2015) will not be met even if PV modules are given away!
SEGIS = "VALUE ADDED"

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SEGIS Goals & Scope

- ***SIGNIFICANTLY*** ***Advance Inverters, Controllers & Energy Management Systems to maximize value to the Consumer & Interconnected Utilities***
- ***Scope***
  - ***PV Systems for High-value Residential and Commercial Applications (100W – 250kW)***
  - ***PV Systems using Advanced Energy Management, Utility Interaction, Technology Advances and Communications***
  - ***Building Energy Management + PV Systems AND Hybrid/Micro-grid Applications that Utilize Energy Storage***

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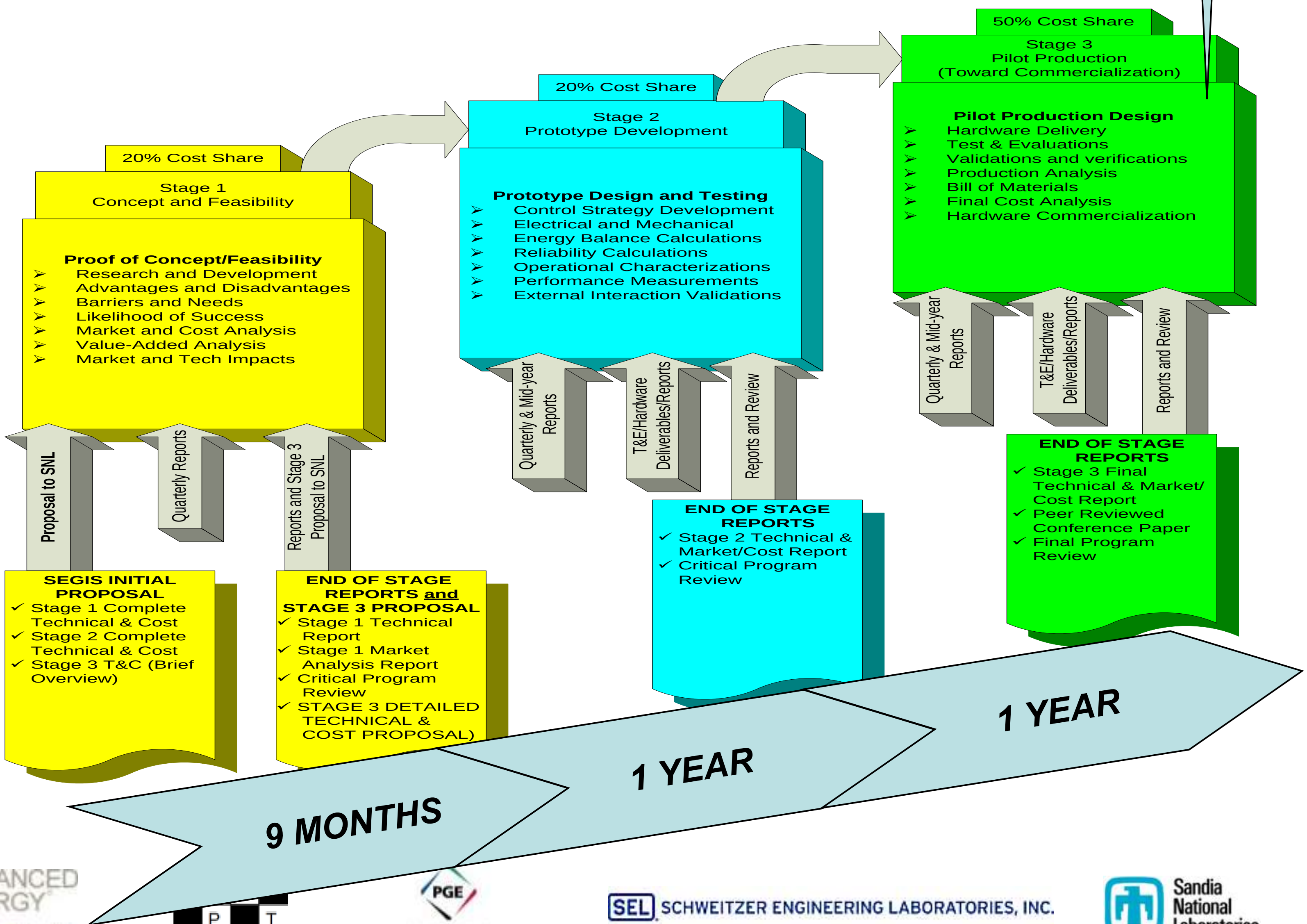
“SEGIS” TIMETABLE

We are Here



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Still Needs Further Work

- *System Topologies – (Low V to 1000V)*
- *Longer System Lifetime (30y goal)*
- *Optimized Costs/Lifetimes*
- *Energy Management Optimizations*
- *System and Component Reliability*
- *Communications for PV Grid Interoperability*
- *Safety and Fire Detection/Mitigation*

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SEGIS Technology Demonstration

Solutions for High Penetration Solar PV

Steve Hummel
VP of Engineering
AE Solar Energy

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September, 20, 2011

Advanced Energy and PV Powered

A leading, global supplier of:

- *Power conversion and control technologies*

To the world's most demanding markets:

- *Renewable energy*
- *Thin film*

By creating best-in-class products and services through:

- *Innovative technology*
- *Life-cycle performance - quality, reliability and uptime*

PV Powered was acquired by AE in 2010

The SEGIS Story

- The DOE program, managed by Sandia, was designed to catalyze partnership and productization
- The tenets of the SEGIS request were on point for motivating new solutions to real problems
- The PV Powered vision aimed to attack the key barriers to high penetration of PV with a systems engineering approach
- We aspired to be bold and change the industry
- PV Powered won a Stage 1 award in 2008
- Stage 2 and 3 were down select stage gates, reducing the number of teams to four finalists
- We are wrapping up our SEGIS three-year program
- We have recently been awarded a SEGIS-AC program

PV Powered SEGIS Program

- 5 Discrete Tasks formed the original vision

Task	Description
1	Advanced MPPT
2	Energy management systems integration
3	String level monitoring and control
4	Solar resource forecasting
5	Advanced utility communications and Control

- A 6th task was added later: The Glue

Task	Description
6	System integration

SEGIS Database and API

Goals

- Provide a virtual ‘home’ for SEGIS inverter system data
- Provide flexible interface to the data
- Translate data to information for
  - Robust solutions, service, support
  - Internal product reliability initiatives
  - External system owners, developers, integrators
  - Other smart grid stakeholders
- 2-way communications between database and secondary controller
- Commercialization of database, API, and front end applications

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Industry Trends and Observations

- This is a Photons to Dollars challenge
- Reliability and durability remain foundational elements
- Current metrics for efficiency, energy harvest and cost are insufficient
- The industry needs to move from simple and static boxes to intelligent, dynamic and responsive systems
- Energy harvest quantification requires sophisticated tools
- The PV industry needs to provide complete solutions and systems that enable sites large and small to operate as single generators, and multiple sites to operate in a coordinated and intelligent fashion as best serves the regional requirements

We're In This Together

- PGE, NPPT and SEL were selected because they shared the vision and passion for driving high-penetration PV
- Today's grid and standards will need to morph to enable high integration levels of distributed generation solutions
- This innovative change agent work is challenging, and no individual company can do this alone – partnership and collaboration is required
- PV systems need to mature towards stable, dispatchable, controllable, cost-effective energy sources
- These kinds of solutions cannot be fully qualified in the lab
  - We need partners to collaborate on field testing and refinement

Our Request

- We seek your feedback, your input and your partnership in refining, testing and proliferating these innovative solutions
- We welcome your interaction – let's make this a conversation, not a presentation
- The live demonstration is intended to show some possibilities and spur discussion, but we are anxious to hear how this approach aligns with *your* vision
- We need your help influencing standards bodies to make sure changes currently being discussed (like 1547.8) leaves room for the solutions we are demonstrating
- Challenge us – we seek a rich conversation
- Enjoy the day

Today's Conversations

- The morning presentations focused on
  - Utility Interactive Controls
  - Synchrophasor-based Island Detection
  - Maximizing Energy Harvest via MPPT Optimization
- The afternoon demonstrations
  - Prologis Park synchrophasor test bed
  - 2 groups – 1:15 and 3:15 departures
- The afternoon presentations
  - State of UIC technology
  - High Penetration Issues and Options

PARTNER INTRODUCTIONS

Renewable Integration for Oregon's energy future

Mark Osborn
PGE Smart Grid Manager
September 20, 2011

Portland General Electric

Leading the way to the future

Biglow Canyon
- *$1 billion*
- *217 turbines*
- *450 MW nameplate capacity*

No. 10 in U.S. for total MWs
- *American Wind Energy Association (2009)*

No. 3 in U.S. for utility wind ownership
- *American Wind Energy Association (2009)*

Early leadership in Pacific Northwest
- *100% of Vansycle Ridge output (1998)*

Early leader in utility ownership of solar projects
- *ProLogis 1 & 2*
- *ODOT Solar Highway*
- *Baldock 1.75 MW under construction*

No. 10 in West for total solar MWs produced
- *Solar Electric Power Association (2009)*

No. 10 in U.S. for IOUs with most total annual cumulative solar MWs

Federal Highway Administration Award for Environmental Excellence *(Solar Highway)*

100% deployment of smart meters in service territory

Electrification of transportation leadership
- *Location of choice for EV deployment*

Green low-impact hydro
- *Pelton Round Butte (winner of Edison Award for innovation)*
- *Sullivan*

No. 1 in # of renewable customers

Boardman biomass project

Salem Smart Power^{sm} Project *(stimulus)*

America’s First Solar Highway

- SunWay 1, LLC Owns and Operates
  - PGE (managing member)
  - US Bank (tax equity investor)
  - United Fund Advisors
  - Energy Trust of Oregon
  - PGE’s Clean Wind Fund customers

Array is approximately 600 feet long
594 Solar Panels—Sunmodule 175 manufactured by SolarWorld
Panels wired into strings of 11 panels to get 480 VDC
54 individually fused sections
Inverter - One PVP 100 kW manufactured by PVPowered
Remotely monitored to assess performance of array
Transformer - 12.7 kV to 480 V

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ProLogis Solar Project Details

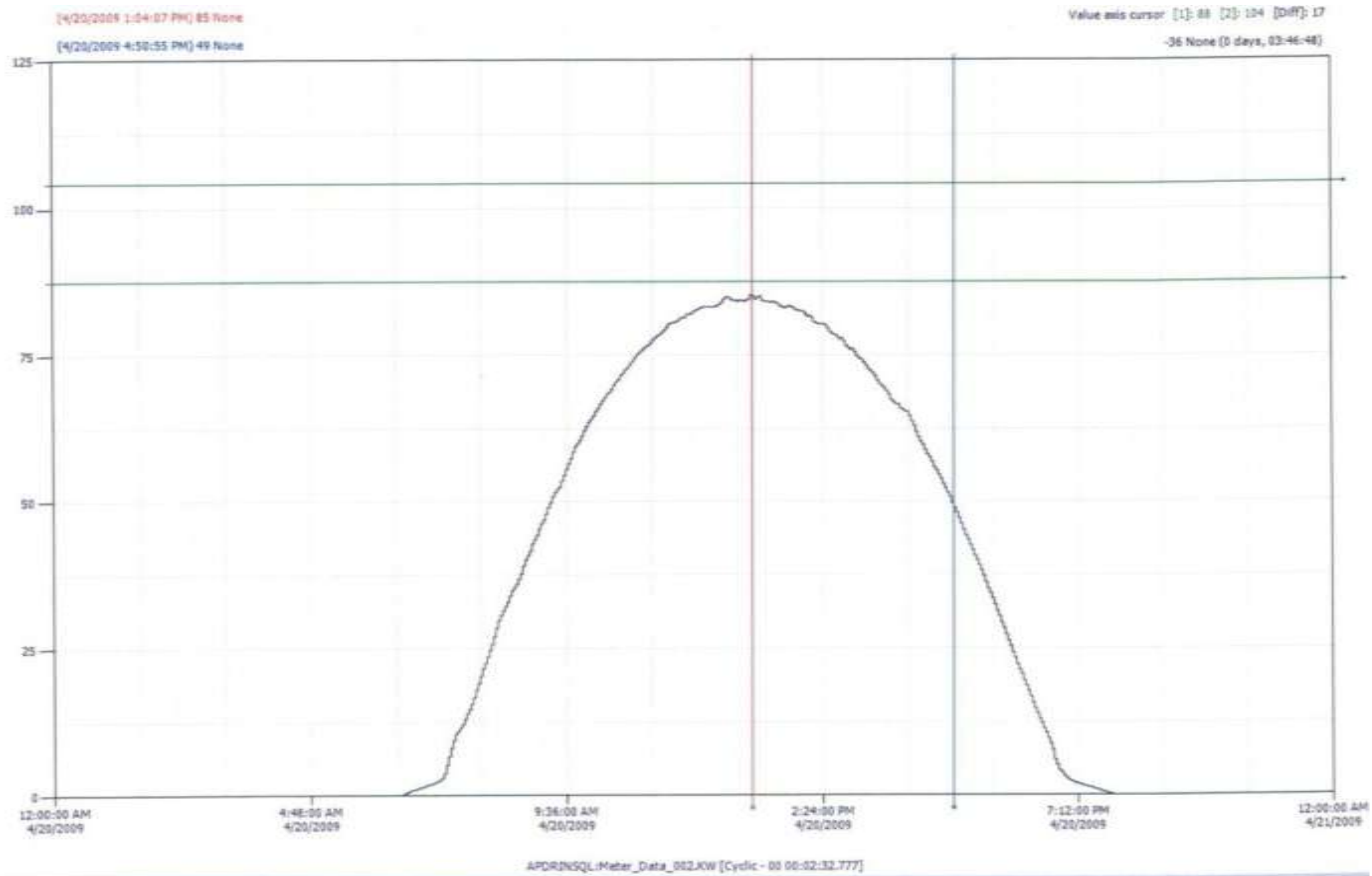
- ***Output: 3.5 MW DC***
- ***Ten rooftops***
- ***Installed December 2008 & July 2010***

SunWay 2&3 LLCs – Project Partners
- PGE (managing member)
- US Bank (tax equity investor)
- Energy Trust of Oregon
- PGE's Clean Wind Fund customers

Financing: Third Party flip structure
- Oregon Business Energy Tax Credit (BETC)
- Federal Investment Tax Credit (ITC)
- Accelerated Depreciation

Technology
- NW Solar Solutions and Solar Integrated Technologies - installers and Building Integrated Photovoltaic (BIPV) panel provider
- United Solar Ovonic ("UNI-SOLAR") amorphous silicon solar laminate ("thin film")
- SatCon inverters

Ideal Solar Production Curve



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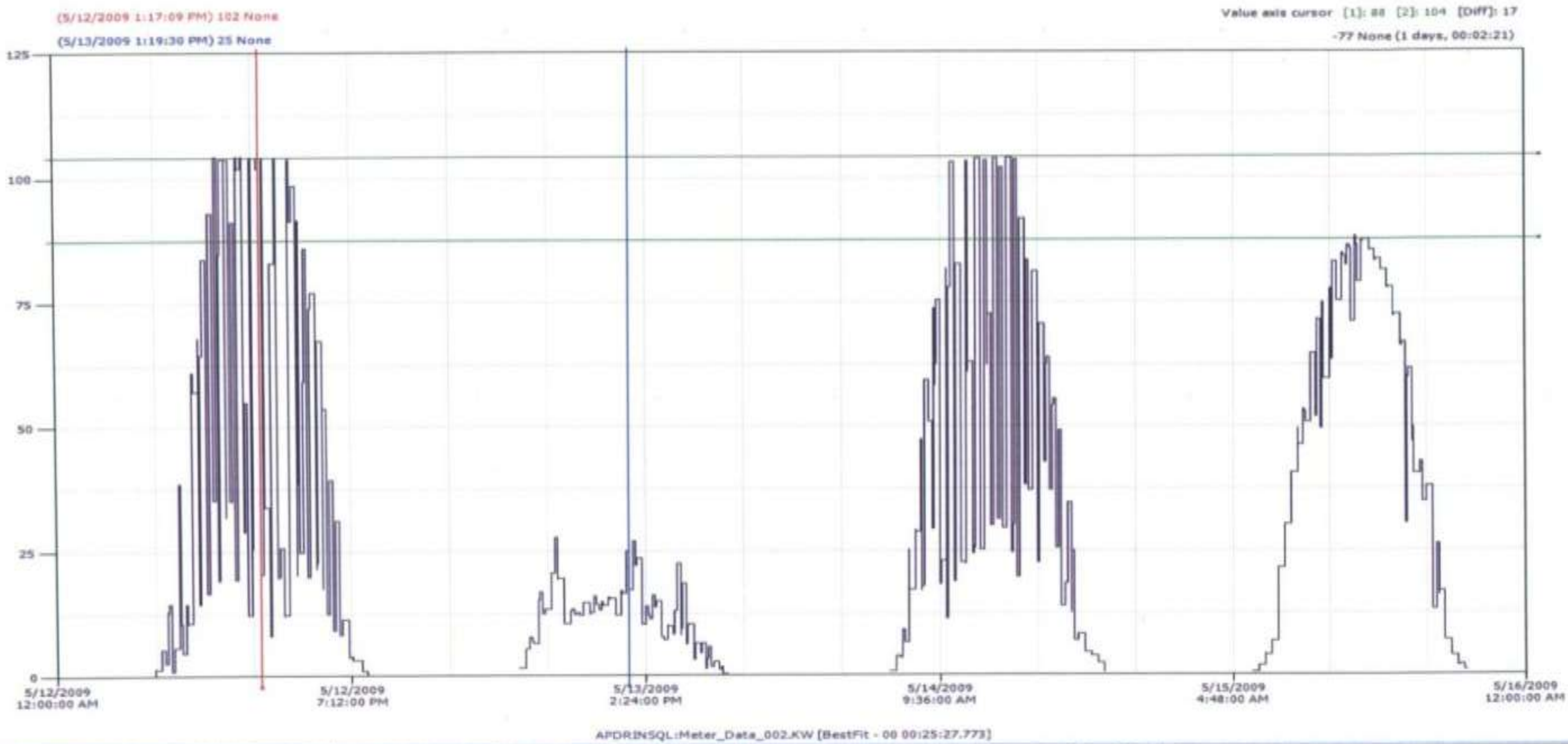
Oregon Typical Production



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6/3/2009 4:42:17 PM

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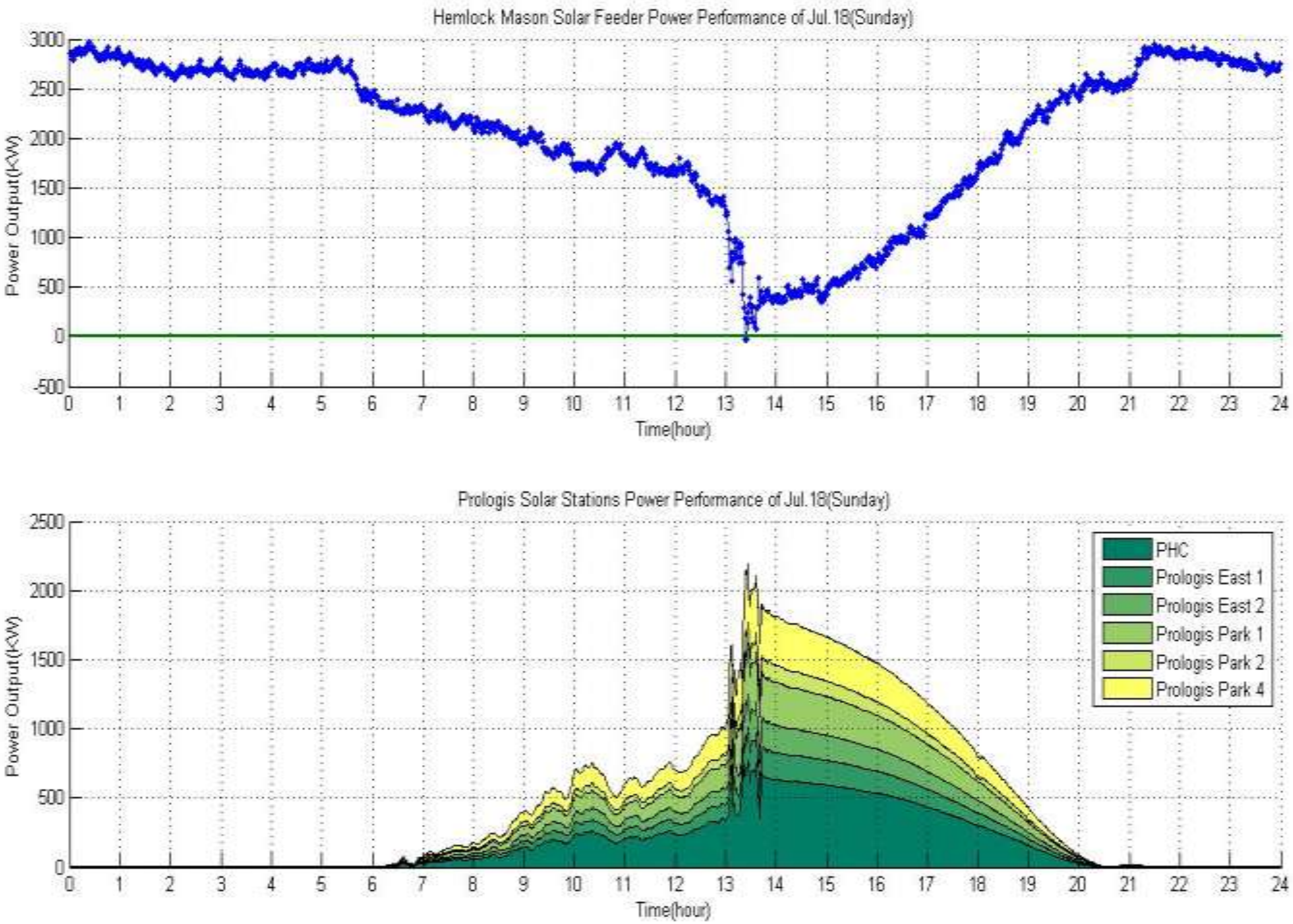
At Conclusion of SEGIS Phase 2:

- Our Research showed a need to:

  - Compare advantages/disadvantages of various methods for islanding detection issues
  - Explore elements of synchrophasor information transfer between substation/reference and inverters. Also look at slower data rates.
  - Examine feeder voltages and impact on substation equipment.
  - Enable NIST Smart Grid Standards for solar inverters
  - New comm messaging for inverters to play well with the grid

What's High Penetration Solar?



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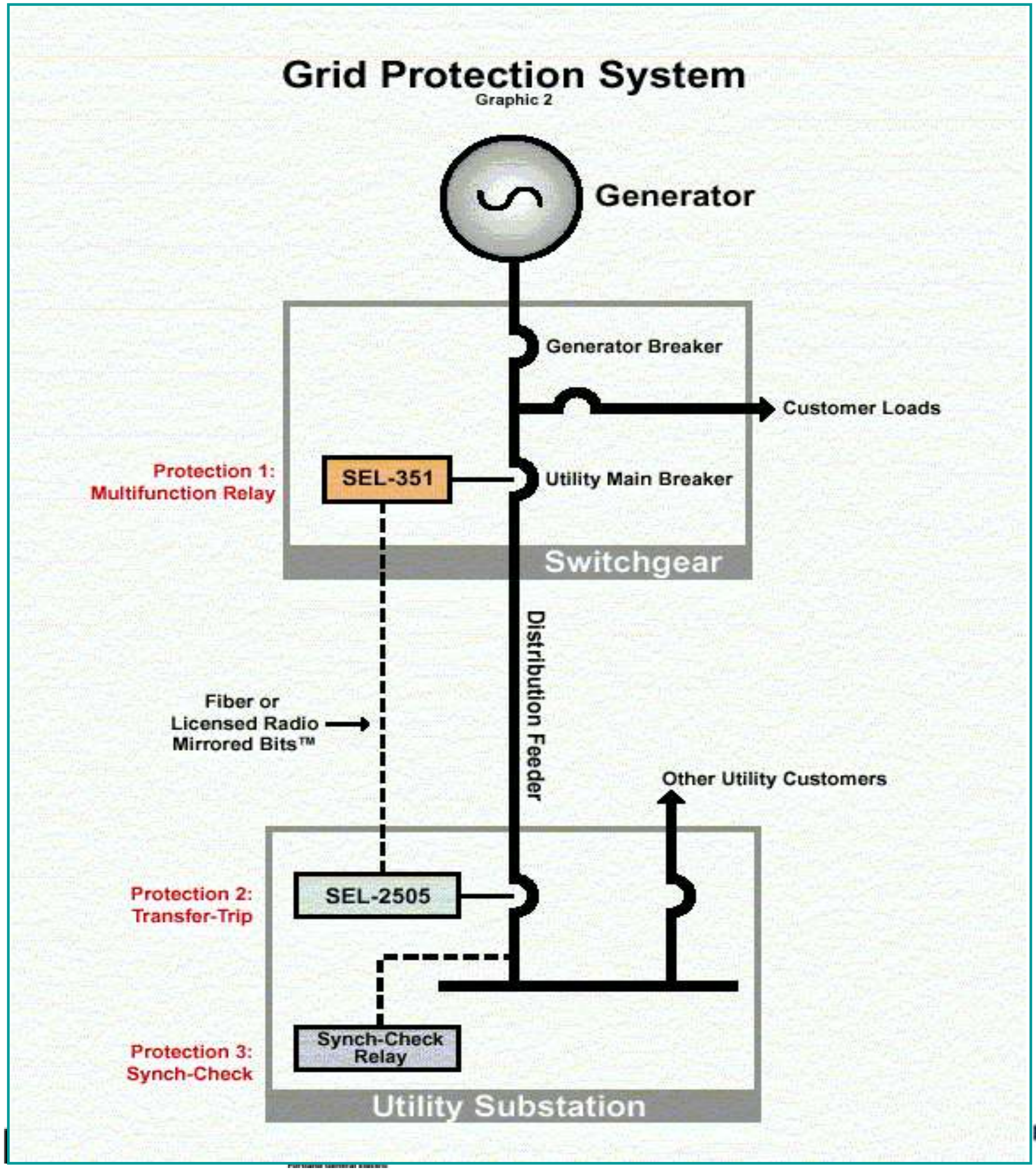
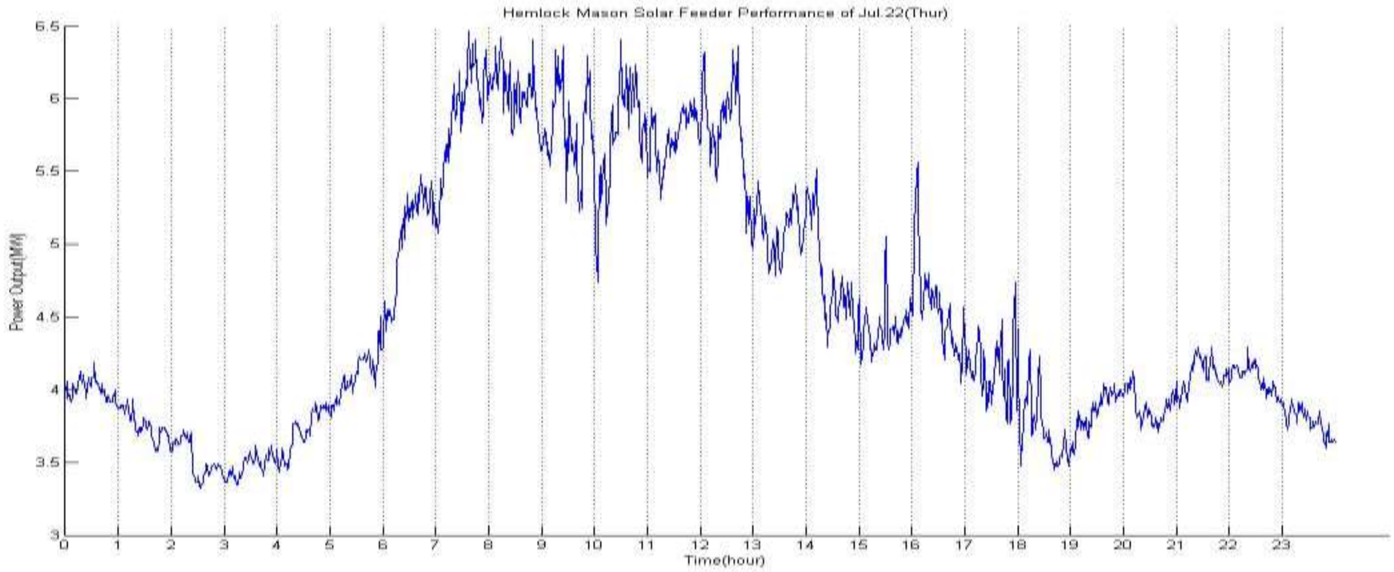
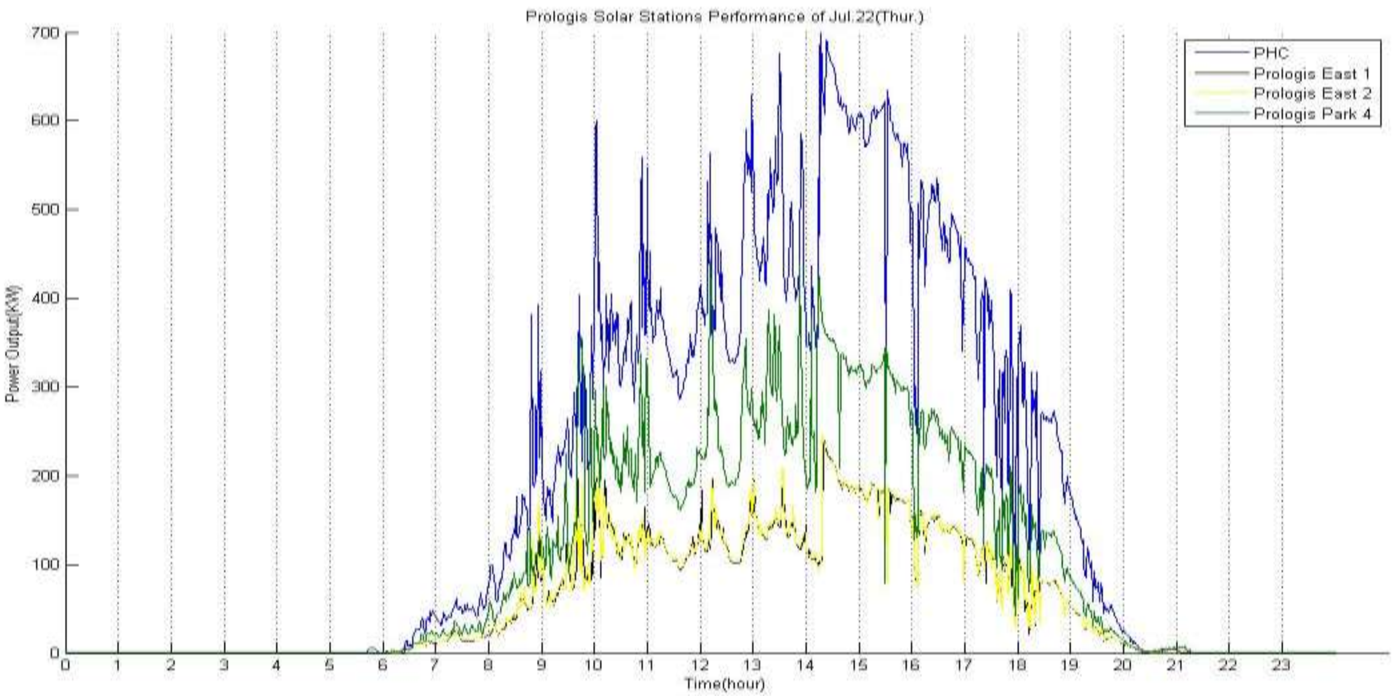
What's the Impact of Islanding?

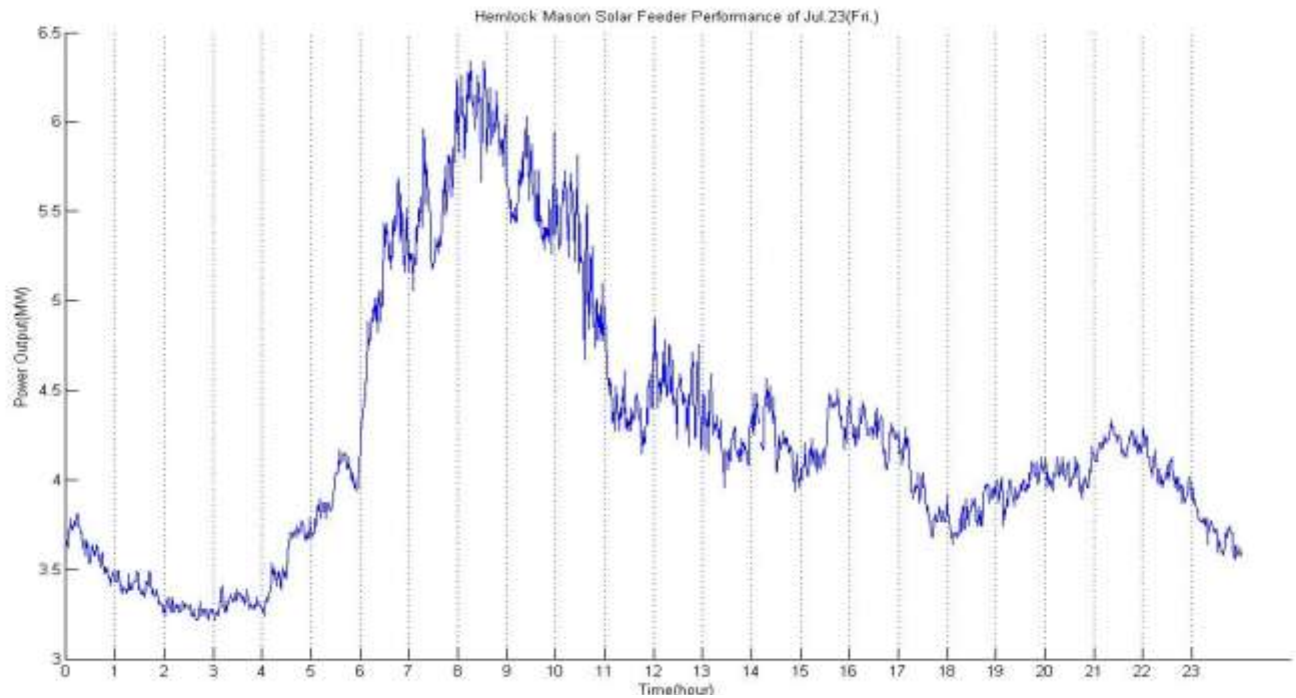


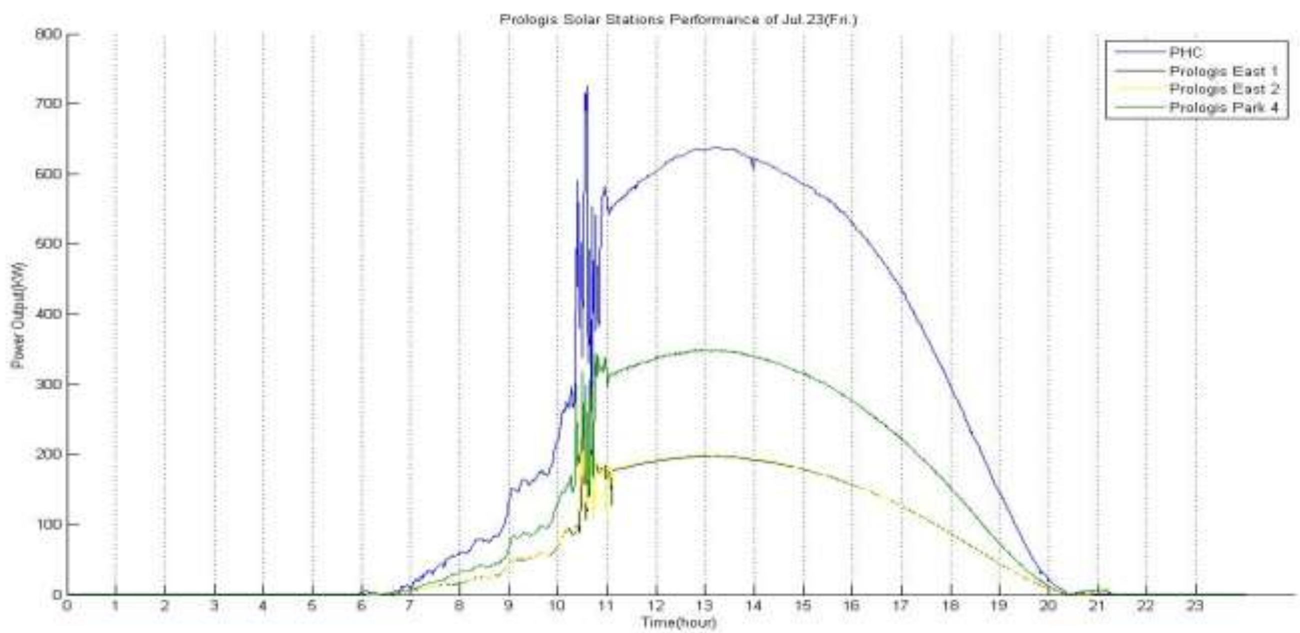
Which Islanding Protection Methods Work Best?

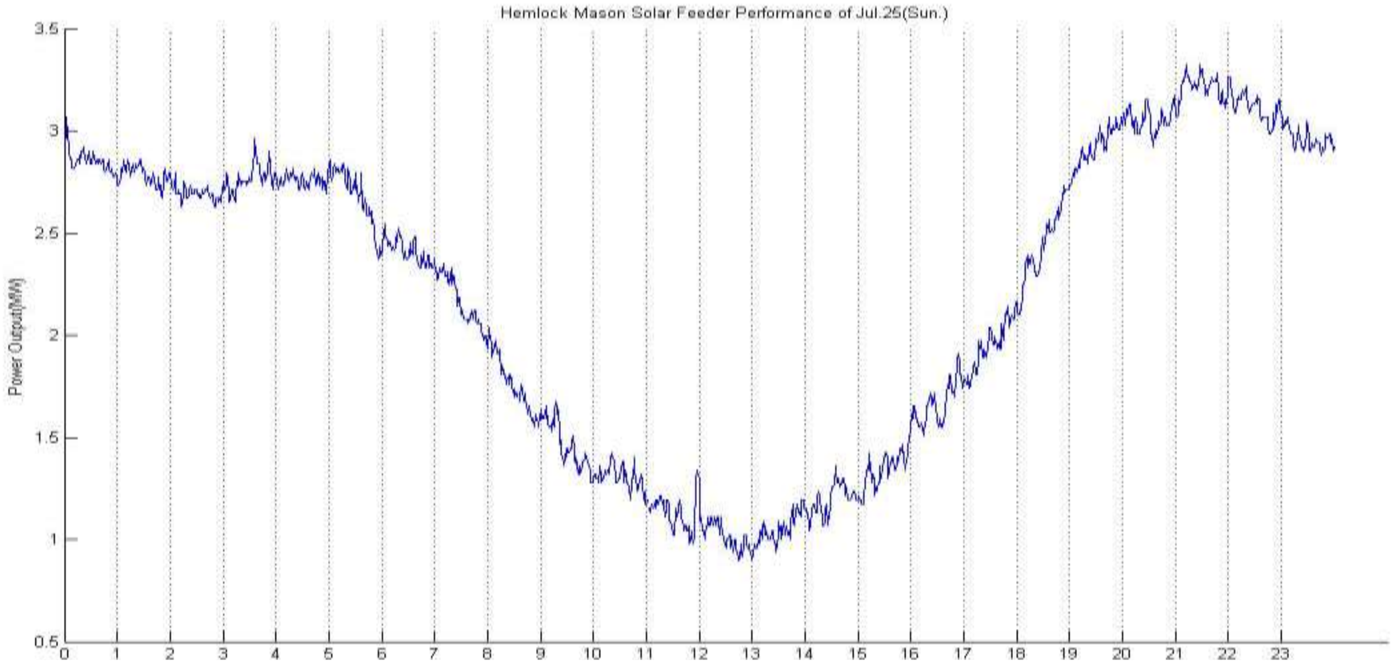
- Hot-line blocking (Substation)
- Feeder-load monitoring (SCADA)
- Transfer-trip (Substation & Comm)
- Power line carrier (Comm)
- Synchrophasor information for islanding issues (Reference & Comm)

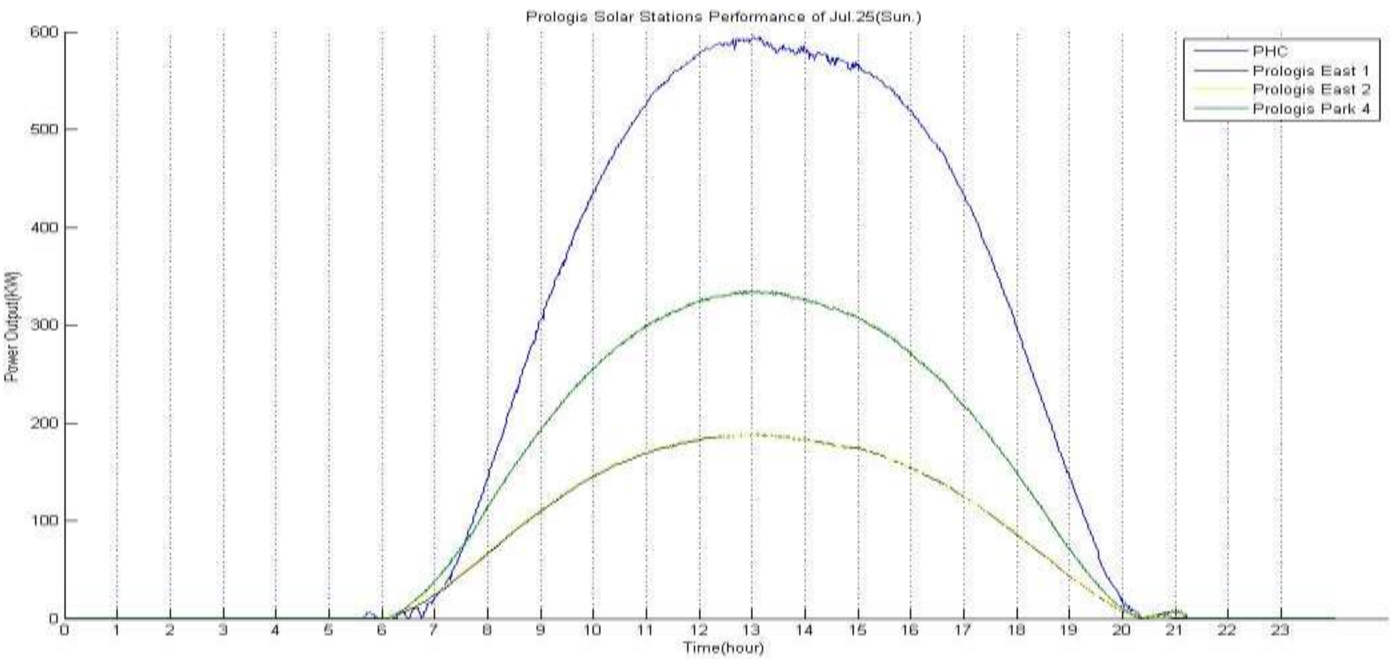

Hemlock Mason Solar Feeder Performance of Jul.22(Thur)
Power Output(MW)
Time(hour)


Prologis Solar Stations Performance of Jul.22(Thur.)
PHC
Prologis East 1
Prologis East 2
Prologis Park 4
Power Output(KW)
Time(hour)

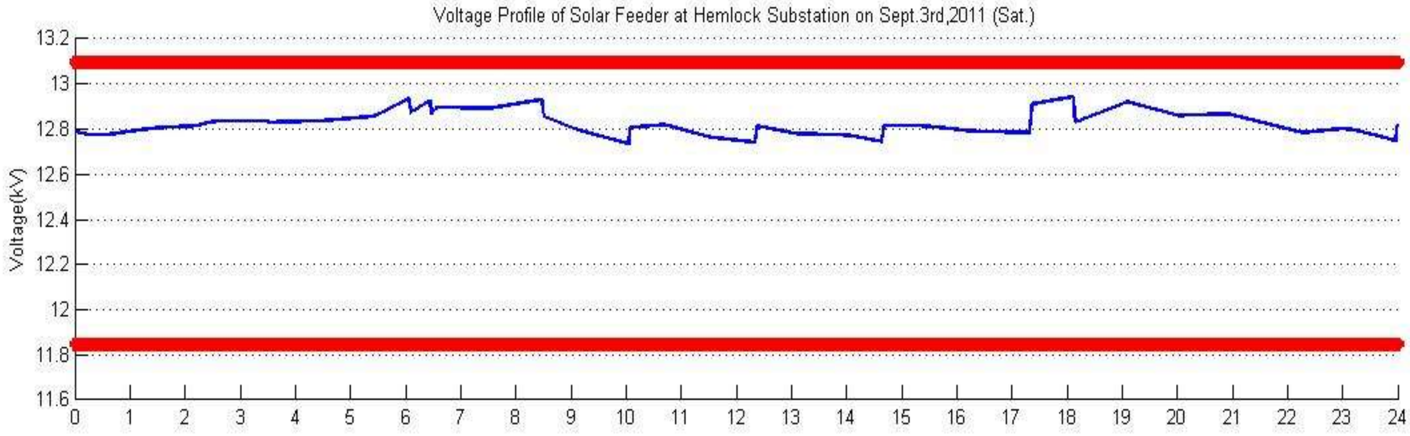

Hemlock Mason Solar Feeder Performance of Jul.23(Fri.)
Power Output(MW)
Time(hour)

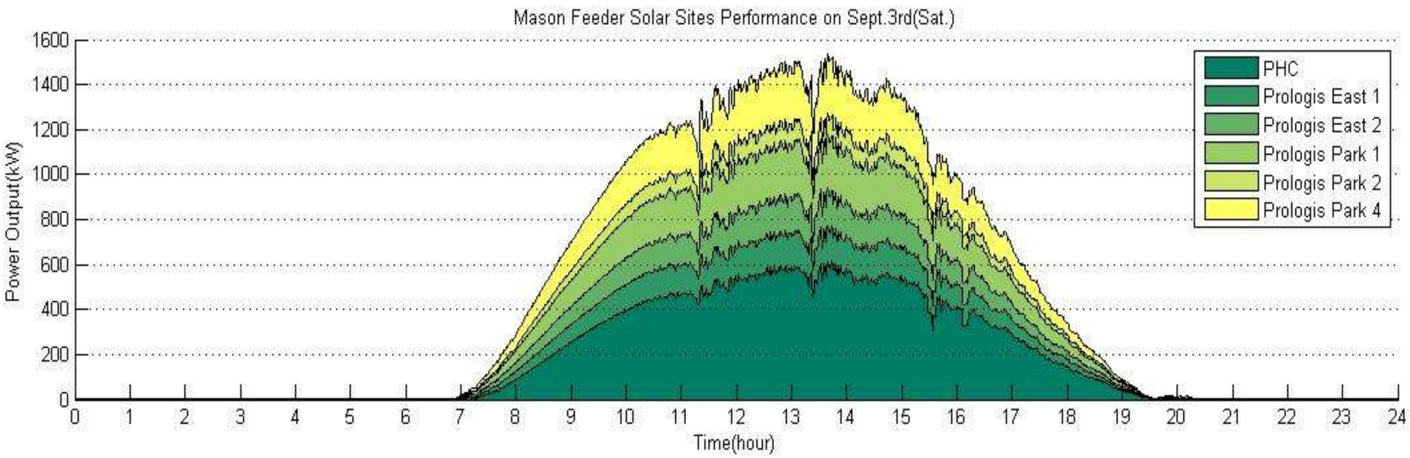

Prologis Solar Stations Performance of Jul.23(Fri.)
PHC
Prologis East 1
Prologis East 2
Prologis Park 4
Power Output(KW)
Time(hour)


Hemlock Mason Solar Feeder Performance of Jul.25(Sun.)
Power Output(MW)
3.5
3
2.5
2
1.5
1
0.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23


Prologis Solar Stations Performance of Jul.25(Sun.)
PHC
Prologis East 1
Prologis East 2
Prologis Park 4
Power Output(KW)
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Time(hour)

What are the Voltage Impacts to Customers and Equipment?





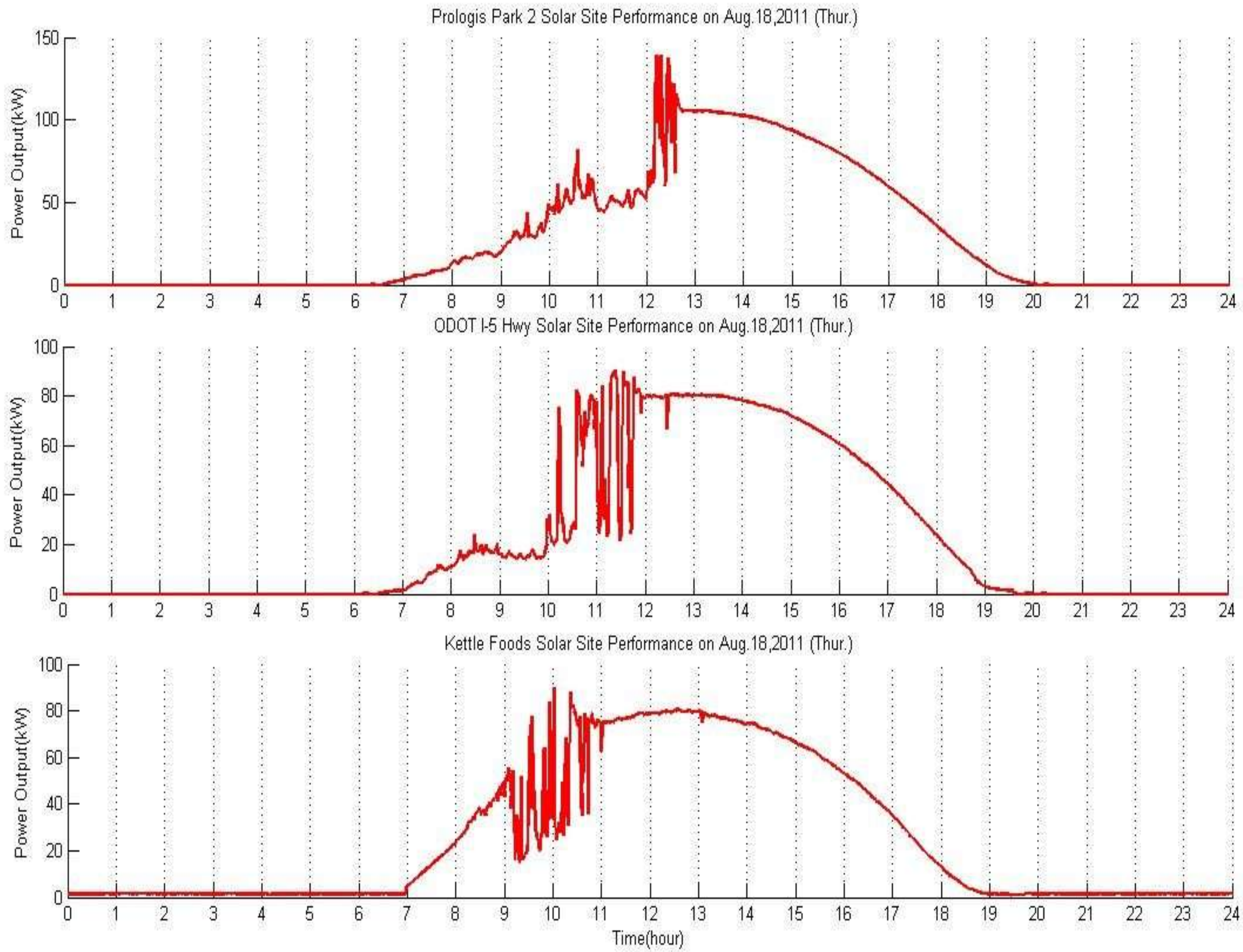
Is Substation Equipment Being Impacted?

- Load Tap Changer:
- Voltage regulation by varying the transformer ratio. Multiple tap change actions may be performed until the voltage is brought within bounds.

Can Solar be a Good Grid Player?

- Explore WECC requirements for large generation and model for inverters
- Examine multiple inverter issues, do they cancel or add, and is there potential for flicker
- Begin developing forecasting/scheduling systems for Solar

Does Solar Diversity Help Us?



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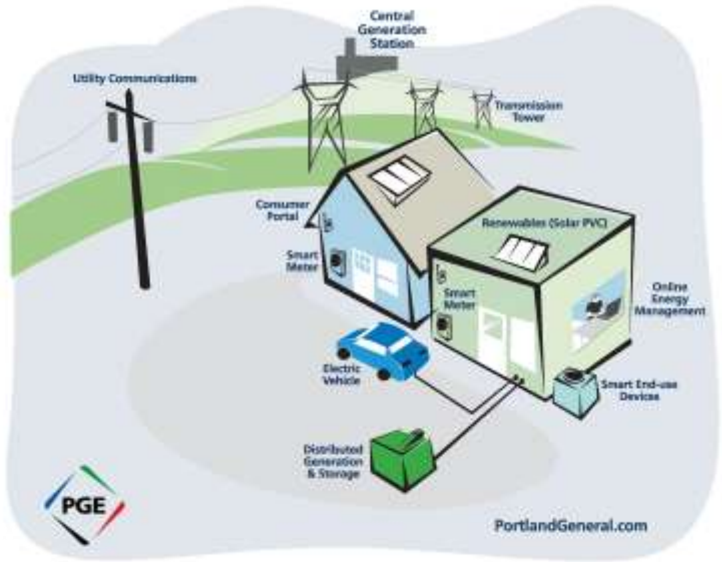
Thank you



<u>For More Information</u>

Mark Osborn, Manager

PGE Smart Grid Program

Phone: **503-464-8347**

Email: **Mark.Osborn@pgn.com**

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SEL - Making PV Generation Safer, More Reliable and More Economical

Dave Whitehead
VP R&D
SEL

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September 20, 2011

Leading Solutions for the Electric Power Industry

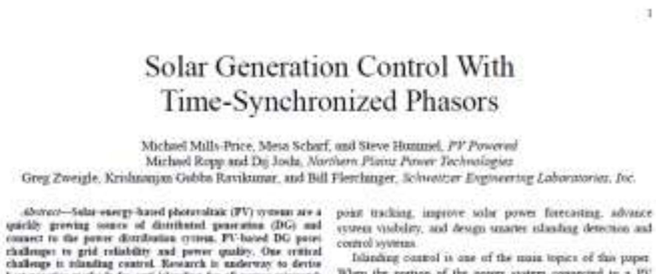
SEL: Trusted Partner for Electric Utilities

- Power Management
- Protection
- Control
- Automation
- Metering
- Integration
- Cybersecurity
- Precise Time
- Integrated Systems
- Panels
- Smart Grid
- Communications for Critical Infrastructure

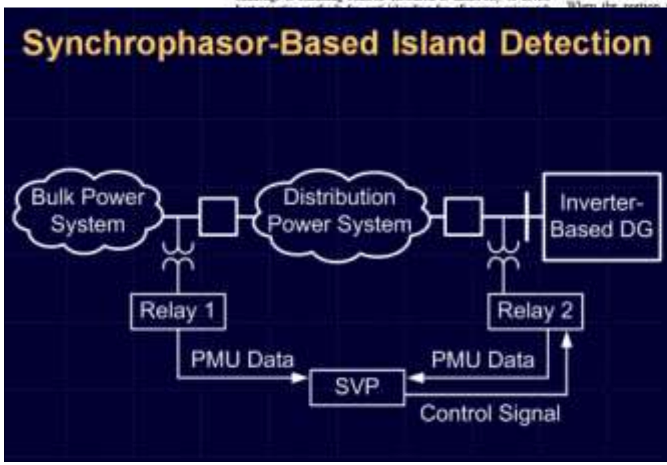
Advances in PV Integration with AE

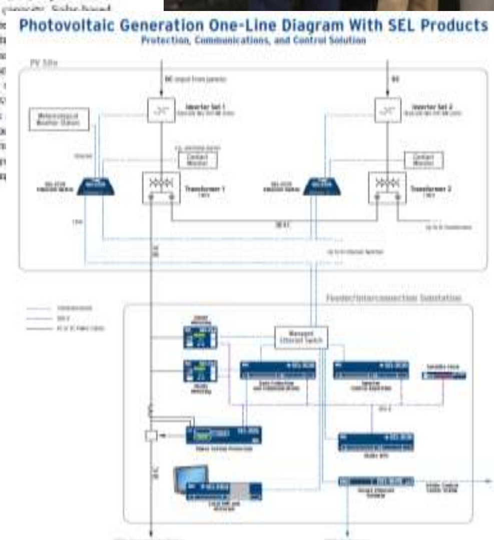
- Integrating Protection, Communication and Control
- Island Detection Algorithm using WAM
- PV Plant Control
- Power Quality/Revenue Meter with PMU

Accomplishments During SEGIS Program


Solar Generation Control With Time-Synchronized Phasors

Michael Mills-Price, Mesa Scharf, and Steve Hummel, *PV Powered*
Michael Ropp and Dij Joshi, *Northern Plains Power Technologies*
Greg Zweigle, Krishnanjan Gubba Ravikumar, and Bill Flerchinger, *Schweitzer Engineering Laboratories, Inc.*





WESTERN PROTECTIVE RELAY CONFERENCE

DISTRIBUTECH CONFERENCE & EXHIBITION

Texas A&M University Relay Conference

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SEL Summary

- Trusted partner for utilities
- Committed to making renewable generation safer, more reliable and more economical
- Looking forward to developing new, innovative solutions for integrating PV generation
  - SEGIS Advanced Concepts
    - Advanced development
    - Integration

Introduction to Northern Plains Power Technologies

Michael Ropp, PhD, PE
President and Principal Engineer
Northern Plains Power Technologies

September 20, 2011

Who we are

- NPPT is an engineering startup company based in Brookings, SD
- Main competencies:
  - Photovoltaics
  - Grid integration of distributed energy resources
  - Microgrid design and controls
- SEGIS focus areas
  - Irradiance forecasting
  - Synchrophasor-based island detection
  - MPPT test protocol
  - Support for new MPPT algorithm development
- During SEGIS period, grew from 3 to 7 employees
- SEGIS enabled NPPT to participate with top-flight team of industry leaders
- SEGIS allowed us to explore a new area, irradiance forecasting, and build capability there

NPPT experience in island detection

- NPPT has roughly 22 person-years of experience on this topic—design, modeling, implementation, characterization/testing
- Co-inventor of the Sandia Frequency Shift method
- Over 30 papers on this and related topics
  - Multi-inverter and multi-DG islands
  - Power line carrier-based island detection
  - Motors in islands
  - Nondetection zones
- Active participant in standards development
  - IEEE 929
  - IEEE 1547
  - IEC 62116

Why do we need a new anti-islanding technique?

- Existing island detection works well in low penetration cases
- Some issues at high penetration
  - Power quality issues
  - Negative impact on system stability
  - Loss of effectiveness in certain multi-DER scenarios
- But the main reason: ***grid support functions***
  - Today's active islanding detection works by creating an abnormal voltage
  - Utilities want PV to help correct abnormal voltages—critical for high penetration
  - Can't do both!
- Solution:
  - Will involve communications
  - Must be fast
  - Must be reliable, without false trips
  - Must bring added value, to reduce overall cost

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OPENING COMMENTS WRAP UP AND Q&A

Steve Hummel

VP of RD&E, AE Solar Energy

Agenda: Morning Presentations

- **9:00-10:00: Utility Interactive Controls**
  - Michael Mills-Price, SEGIS Program Manager, AE Solar Energy
- **10:00-10:15: Break**
- **10:15-11:15: Maximum Power Point Tracking (MPPT): The other half of the energy harvest equation**
  - Michael Ropp, Principal Engineer, Northern Plains Power Technologies
  - Steve Hummel, VP of Engineering, AE Solar Energy
- **11:15-12:15: Synchrophasor-based Island Detection: Solving a critical gap in utility integration under high penetration PV**
  - Mesa Scharf, Director of Solutions Engineering, AE Solar Energy
  - Michael Ropp, Principal Engineer, Northern Plains Power Technologies
  - Michael Mills-Price, SEGIS Program Manager, AE Solar Energy
- **12:15-1:15: Lunch**

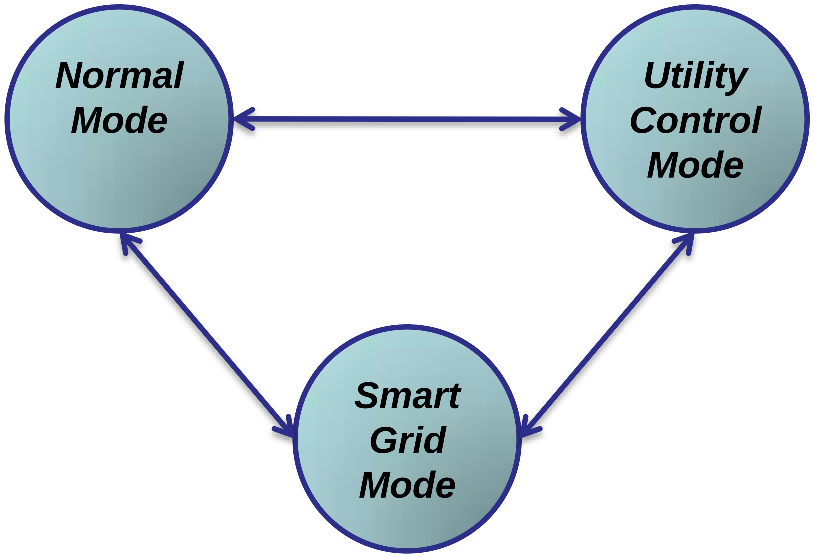
Inverter Controls for Stand-Alone and SCADA Integrated Applications

Michael Mills-Price
SEGIS Program Manager
AE Solar Energy

September 20, 2011

Presentation Overview

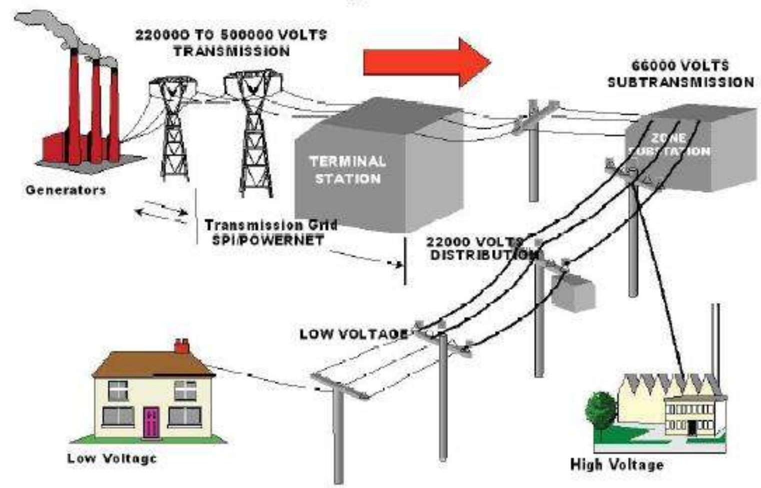
- Distribution System Impacts
  - Volt / VAr control Overview
  - Centralized / Coordinated / Autonomous Control
  - Intermittent Generators
- Function Descriptions
  - Power Factor
  - Curtailment
  - Ramp Rate
- Solutions for Stand-Alone Applications
  - Coordinated Schedule Driven Control
  - Power Factor Pro
  - Field Performance Data
- Solutions for SCADA and Building Energy Management Connected Applications
  - Building Energy Management Systems
  - Utility or ISO Operator SCADA Applications
- Demonstration of SCADA Connected Over-Ride Control

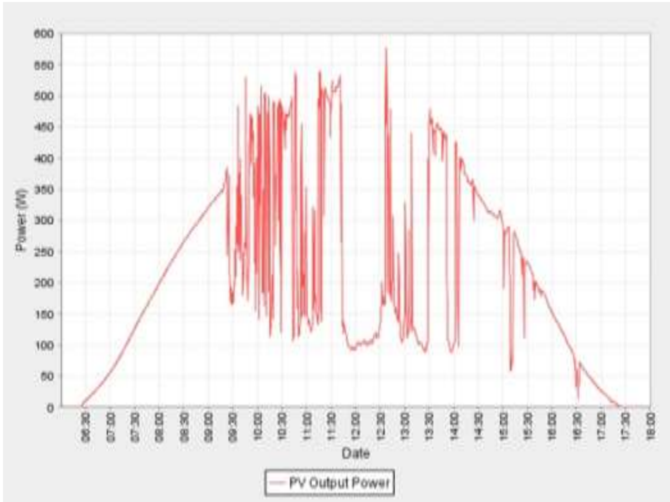


Distribution System Impacts

- Traditional Distribution Networks
  - Designed for radial power flow
  - System voltage limits to all customers
- Distributed Generation Connections
  - MV connection to sub-station
  - MV connection to existing distribution feeder
  - LV connection in distribution feeder
- Increasing Loads / Load Scheduling
  - Modern switch mode power supplies
  - Electric vehicle charging stations
  - Compact Fluorescent Lights
  - Intermittency of Distributed Generators

How electricity is delivered

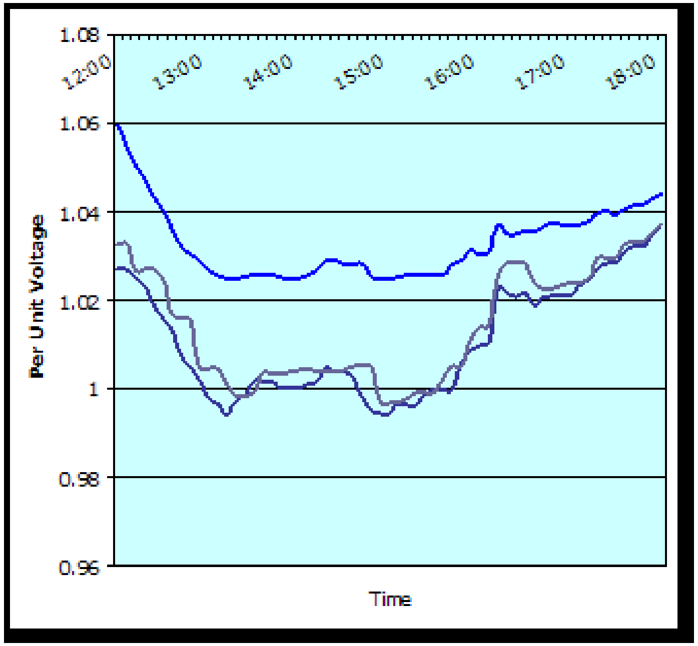




Volt / VAr Control

- Maintaining System Voltage
  - All Customers
  - All loading conditions
- Increase Efficiency
  - Distribution improvements upstream
  - Loss Reductions
  - Improve operating margin (upstream capacity)

- System Control
  - Diverse control techniques
  - Location
  - Feeder configuration
  - Loading
- Distributed Generators as Assets
  - Coordinated VAr delivery $$
  - Improve voltage stability
  - Reducing regulation equipment cycle counts



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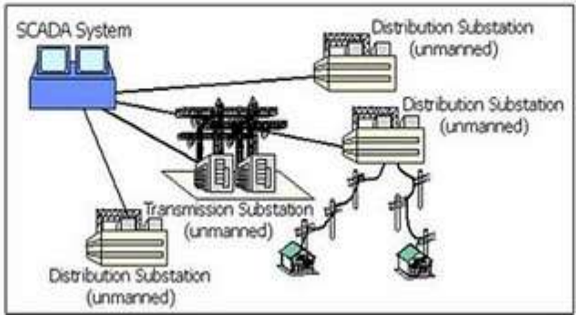
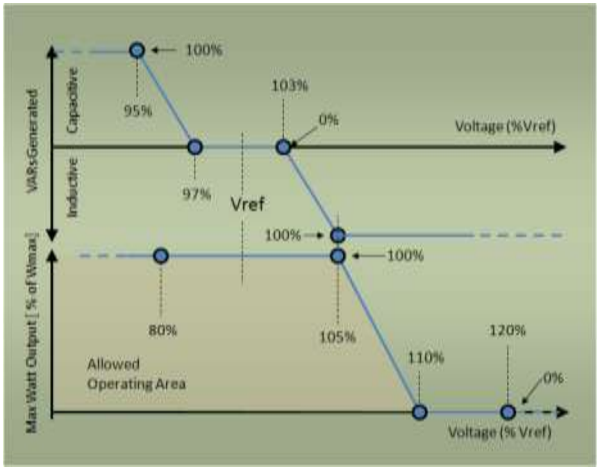
Methods of DG Control

- Centralized Control
  - Decisions made at central distribution control center
  - Supervisory Control and Data Acquisition (SCADA)



- Coordinated Control -- Scheduled Power Factor (SPF)
  - Pre-determined operational modes programmed into DG systems
  - Communications link optional to DG devices
  - DG response is deterministic



- Autonomous Control (smart grid mode)
  - Operational decisions made at endpoints
  - Peer to peer operational control
  - Dynamic voltage regulation
  - Working with standards committees (1547.8 / EPRI)

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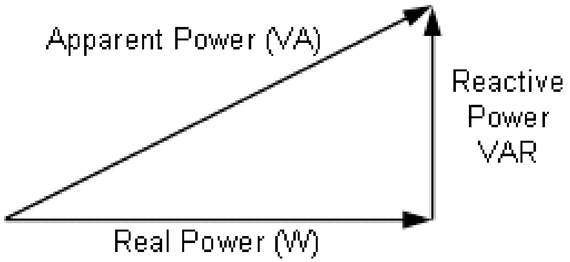
Function Descriptions (Control Parameters)

Function	Description	Range
Power Factor	Allows for varying angle of current with respect to voltage. Allows sourcing and sinking of VAr's	0.9 – 0.9 lead / lag
Curtailment	Allows for reducing system output power. (also called active power throttling)	0 – 100%
Ramp Rate	Allows for controlling the rate at which current (power) increases / decreases	1--57 kW/S
Action Delay	This feature enables pre-defined delays for set-point changes. Allows for smearing of collective response	0-5 minutes
Randomization	This feature randomizes the start time of set-point change based on pre-defined thresholds	0-5 minutes
Remote enable/ Disable	This feature allows for the system to be remotely turned on / off	N/A

Field Results of SPF on East Coast Installation (PEPCO)

- Coordinated scheduled power factor control
  - Time based on historical possible % power output



1. Operate inverters at a leading PF (power factor) of (0.97), absorbing VARs (Voltamps-reactive), during peak output periods where output can potentially be 75%of the peak or greater.

2. Operate inverters at a leading PF of (0.98), absorbing VARs, during intermediate
output periods where output can potentially be 50% up to 75%

3. Operate inverters at a leading PF of (0.99), absorbing VARs, during low output periods where output can potentially be up to 50%.

Time Based Schedule (PEPCO Application)

Month(s)	Start Time	End Time	Power Factor
Jan./Feb.	10:00 am	2:59 pm	0.98
	3:00 pm	9:59 am	0.99
March	10:00 am	10:59 am	0.98
	11:00 am	2:59 pm	0.97
	3:00 pm	4:59 pm	0.98
	5:00 pm	9:59 am	0.99
Apr./May/June/Jul.	9:00 am	9:59 am	0.98
	10:00 am	3:59 pm	0.97
	4:00 pm	4:59 pm	0.98
	5:00 pm	8:59 am	0.99
August	9:00 am	10:59 am	0.98
	11:00 am	3:59 pm	0.97
	4:00 pm	4:59 pm	0.98
	5:00 pm	8:59 am	0.99
September	10:00 am	10:59 am	0.98
	11:00 am	2:59 pm	0.97
	3:00 pm	3:59 pm	0.98
	4:00 pm	9:59 am	0.99
October	10:00 am	10:59 am	0.98
	11:00 am	1:59 pm	0.97
	3:00 pm	3:59 pm	0.98
	4:00 pm	9:59 am	0.99
November	9:00 am	1:59 pm	0.98
	2:00 pm	8:59 am	0.99
December	10:00 am	1:59 pm	0.98
	2:00 pm	9:59 am	0.99

Monthly Schedule Transition

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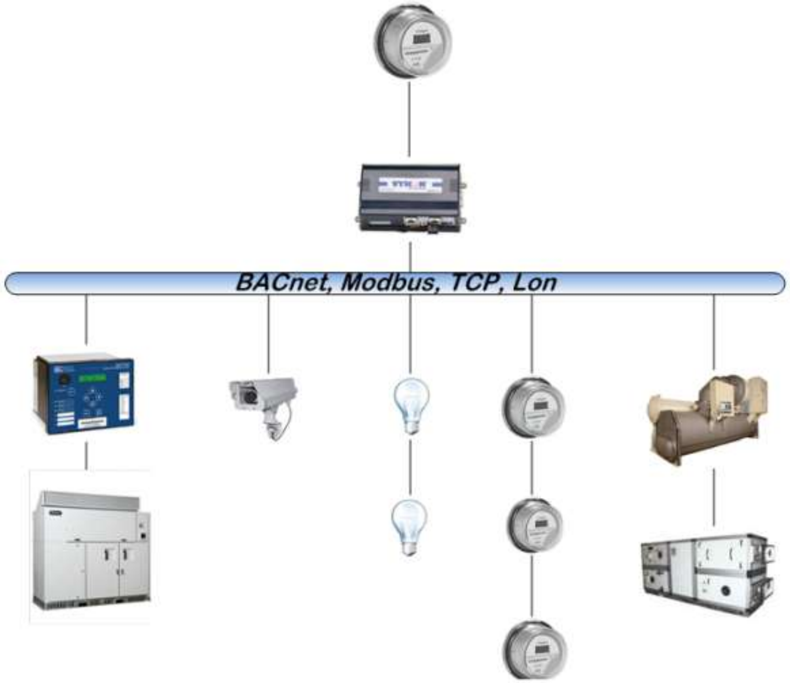
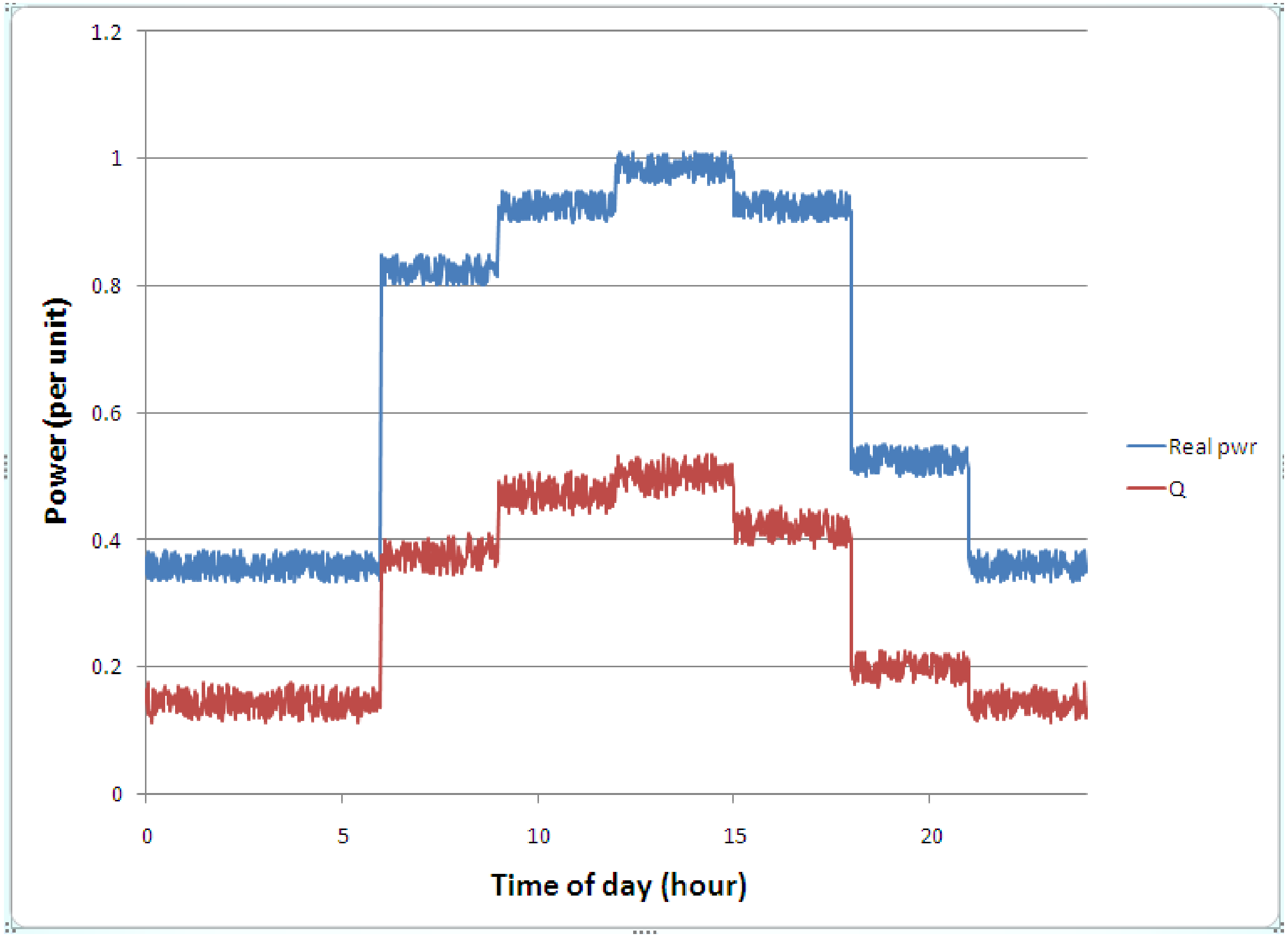
Solutions for Directly Controlled System Applications

Utility Control Mode

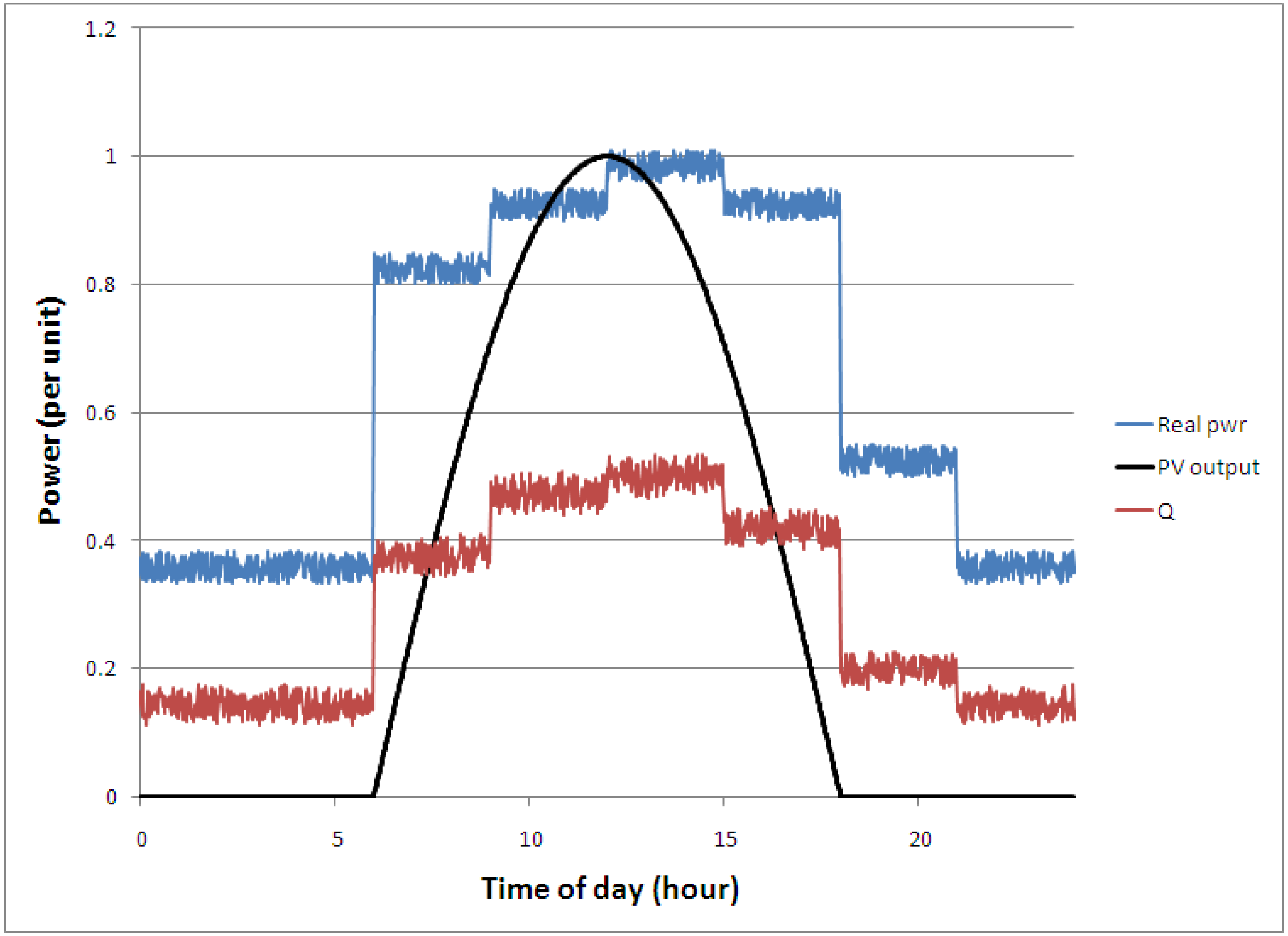
- Building Energy Management Systems
  - Integrated system performance
    - Johnson Controls, Delta Controls, Tridium, Echelon
  - Optimize building controls using solar system as input to controller
    - Reduce demand charges
    - Increase building efficiency
- Utility SCADA Systems
  - Directly control any pre-defined function
  - Remotely set function schedules
  - Control aggregate systems as single asset



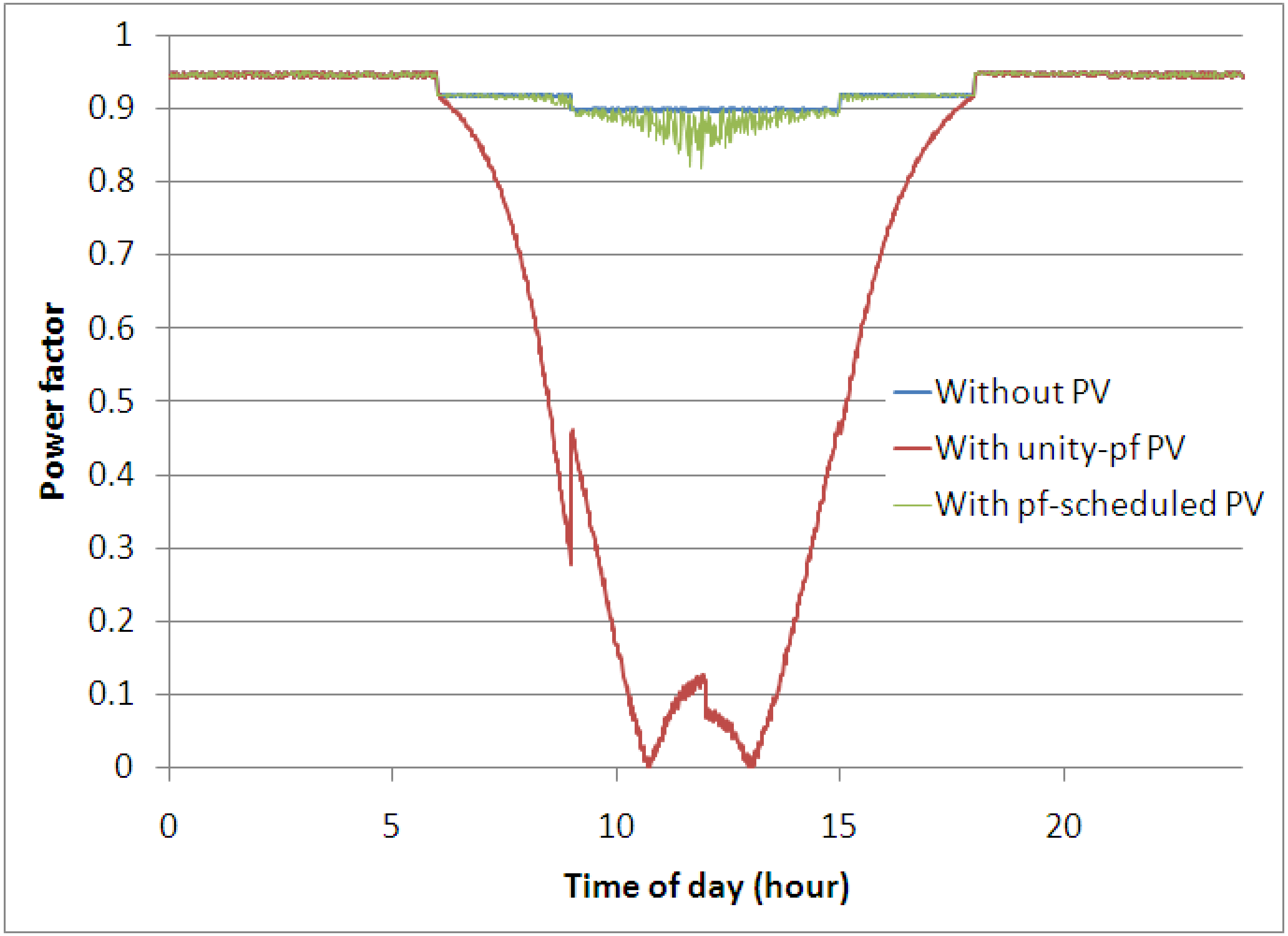
Building Energy Management System Example



Building Energy Management System Example

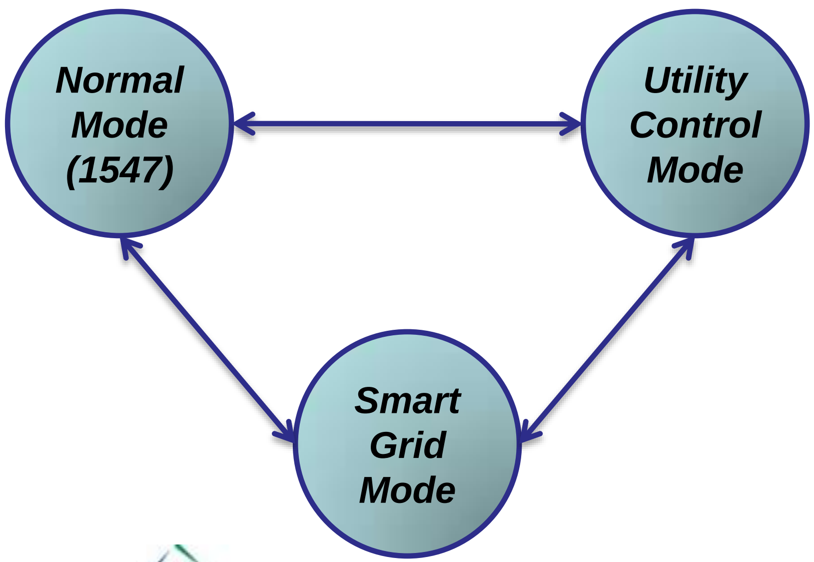


Power Factor Control Moderating Impacts



Summary -- Solutions for Stand-Alone and Directly Controlled PV Systems

- VAr management is critical to maintaining system voltage and efficiency
- PV Penetration combined with ever evolving loads are driving needs for different configurable solutions
- Advanced Energy and SEGIS partners have developed a set of configurable solutions to meet near term customer and utility needs



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Live Demonstration of SCADA controlled PV System

- GenOnSys SCADA System
  - 54 MW Distributed Generators
  - Bio, Solar, Wind, Hydro
  - Control / Monitor / Aggregate

- PV Powered 260 kVA inverter
  - Power factor control
    - 0.9 Leading
    - 0.9 Lagging
  - Curtailment
    - Reduce output power (irradiance dependent)
  - Remote Disable / Enable

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Questions / Comments

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Maximum Power Point Tracking

Steven Hummel
VP RD&E
Solar Power

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PVPowered solaron siteguard

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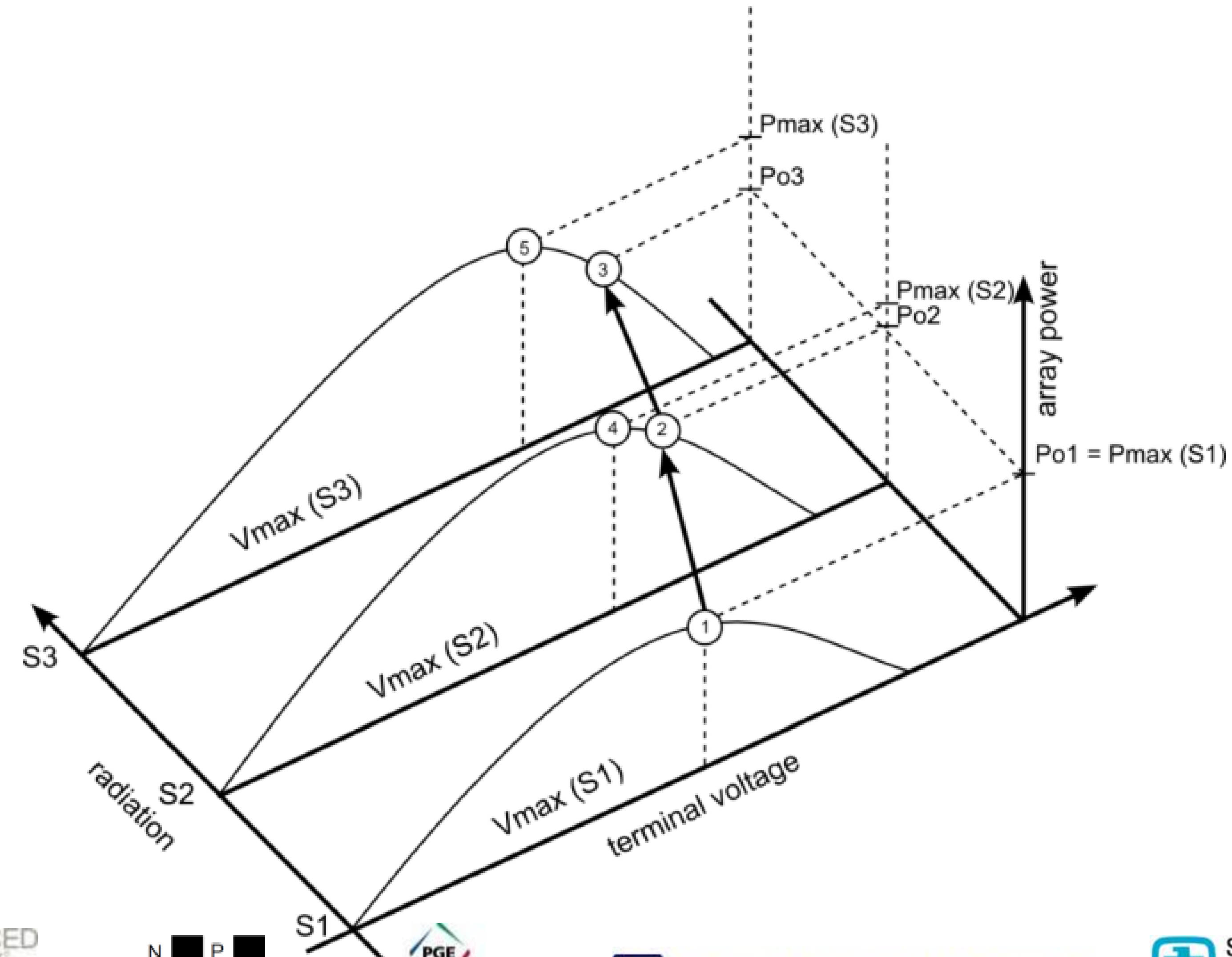
September 20, 2011

The Original Premise

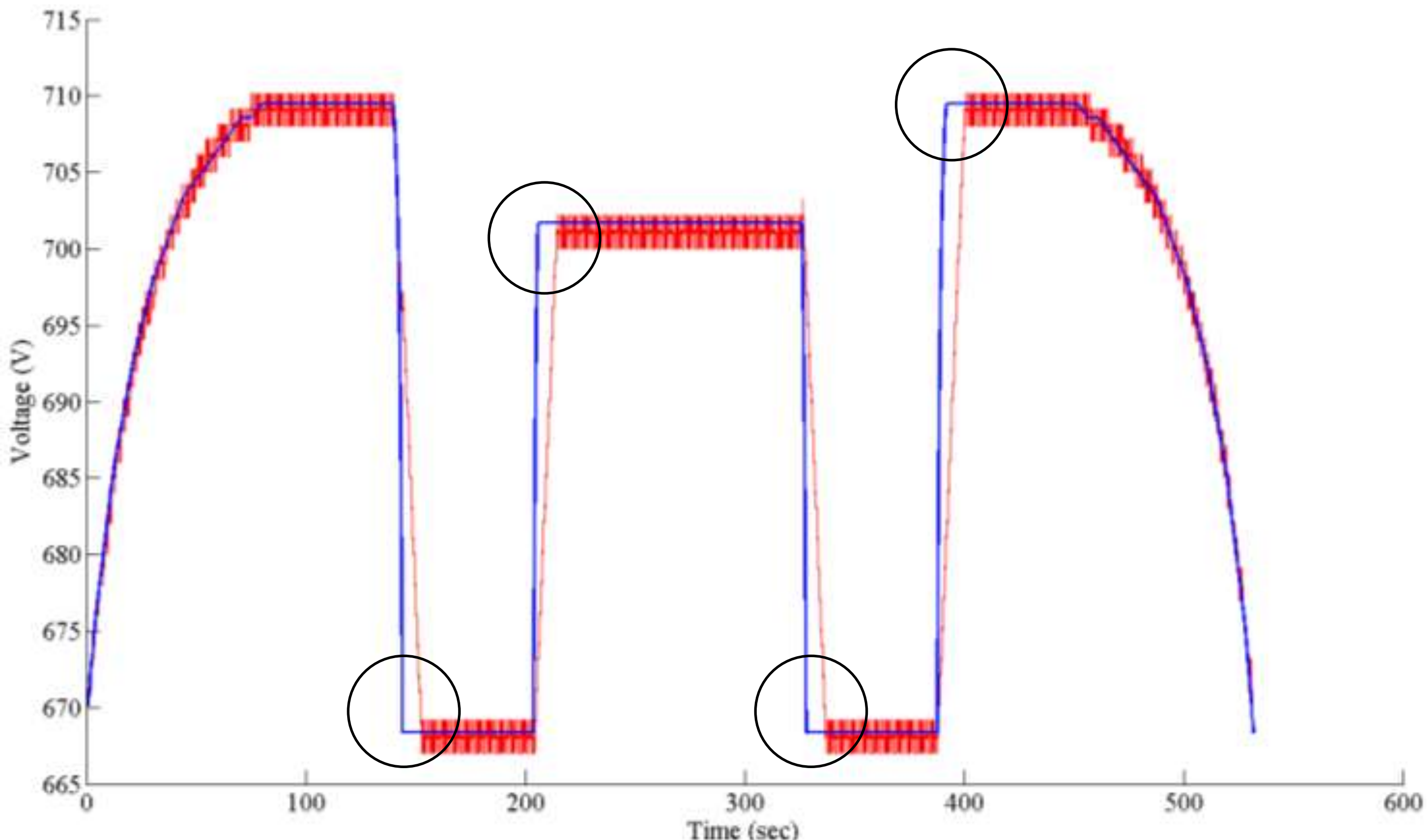
- The "MPPT Efficiency" metric used by the industry is insufficient to compare inverter energy harvest performance
- Different families of solar module technologies will require different MPPT parameters to achieve maximum energy harvest
- There are opportunities to enhance energy harvest via dynamic tuning using solar forecasting inputs
- Synthetic lab validations are a useful step, but energy harvest demonstrations under sun will be the final arbiter
- It would benefit the industry to create and build acceptance of a dynamic test protocol that is grounded in real-world weather

P&O - Loss of tracking



Total Energy Loss – An Additional Metric

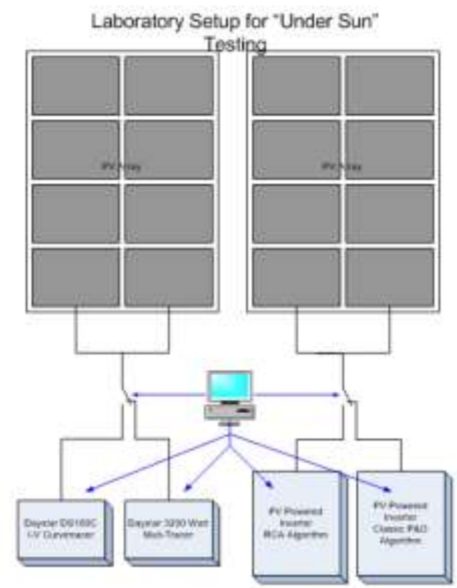
- Classic MPPT efficiency numbers are typically approaching 99.9%.
- An important metric is total energy "lost" from the maximum theoretical harvest.



Under Sun Testing

- Developing Tools
  - Installing solar modules
  - Writing LabVIEW code for collecting data
  - Developing scripts for plotting and comparing results
  - Equipment comparison application specification
  - IV Curve-tracer, Multi-tracer, and Yokogawas

- Establishing Baseline Performance
  - Array to Array Comparisons
    - Tandem array architecture
      - Control vs. Test
    - Sunny, cloudy and overcast
  - Inverter to Inverter Comparisons
    - P&O vs. P&O
    - RCA vs. P&O



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Tour of Testing Facilities

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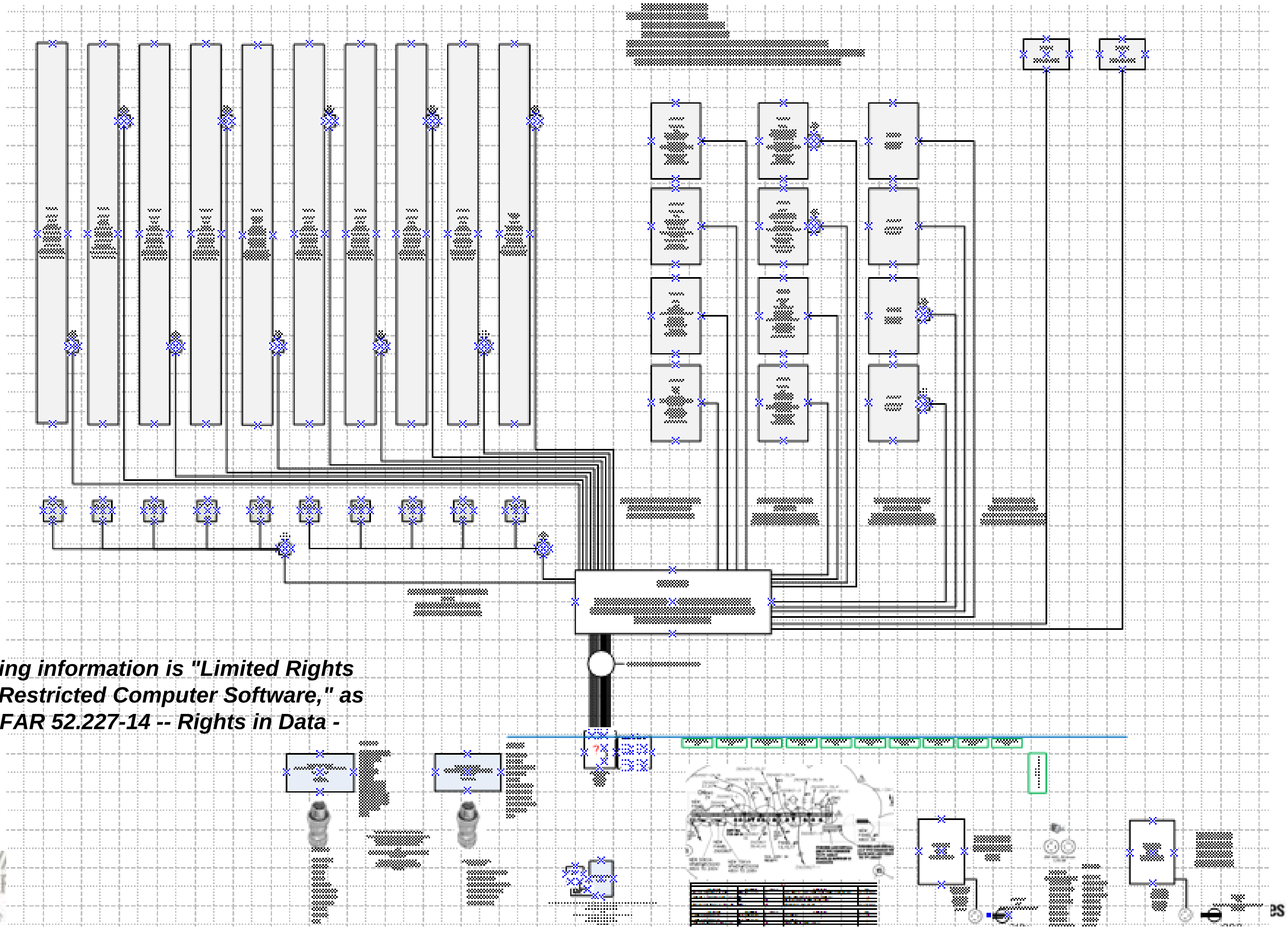
MPPT and Solar Field Layout



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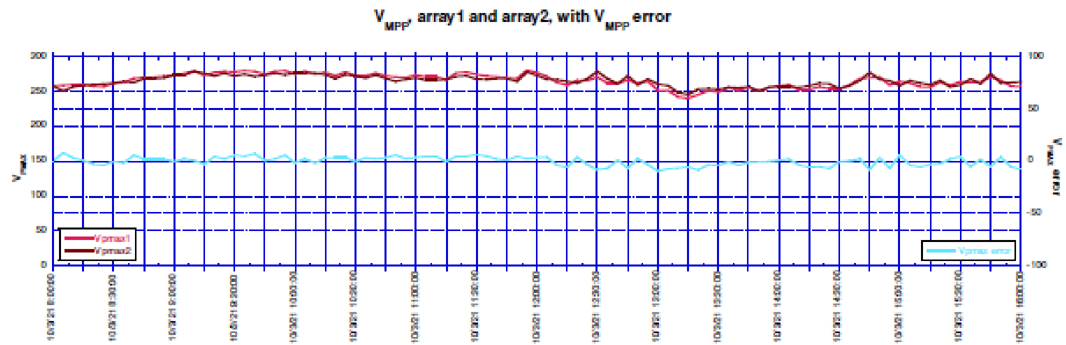
Crystalline Si Cloudy

PVPowered™
Simply More Reliable Solar

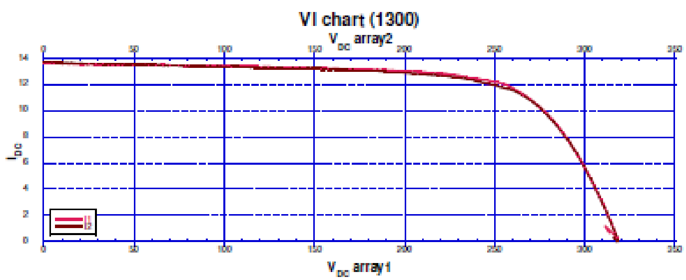
Array to Array Comparison

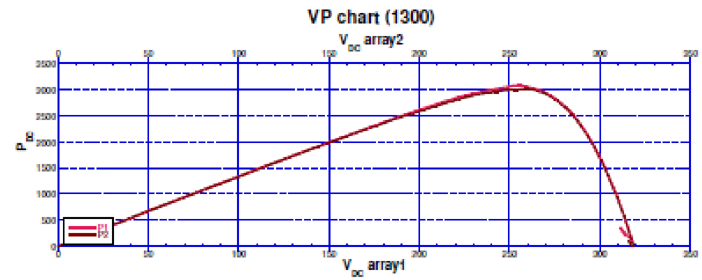
Test Conditions
March 21, 2010
8:00 to 16:00
5 minute increments

	Pmax error
Minimum	0.1
Maximum	276.71
Mean	43.72
RMS	67.82
Std Deviation	52.12
RMS error % of Pmax	2.05 %



	Vpmax error
Minimum	0.052688599
Maximum	9.1948853
Mean	3.7169981
RMS	4.3277617
Std Deviation	2.2281446
RMS error % of Vpmax	1.54 %



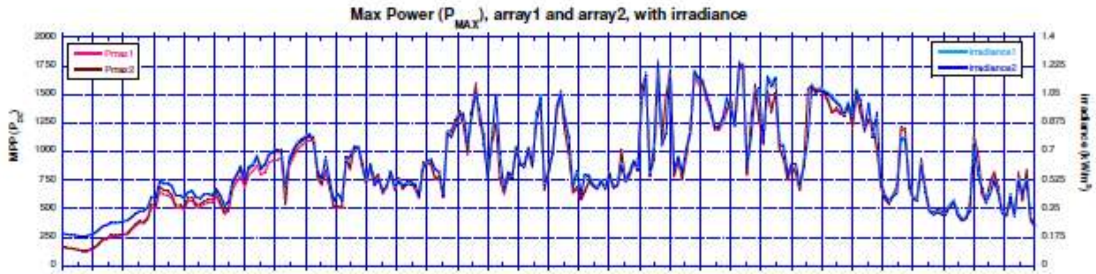


Micro-Amorphous

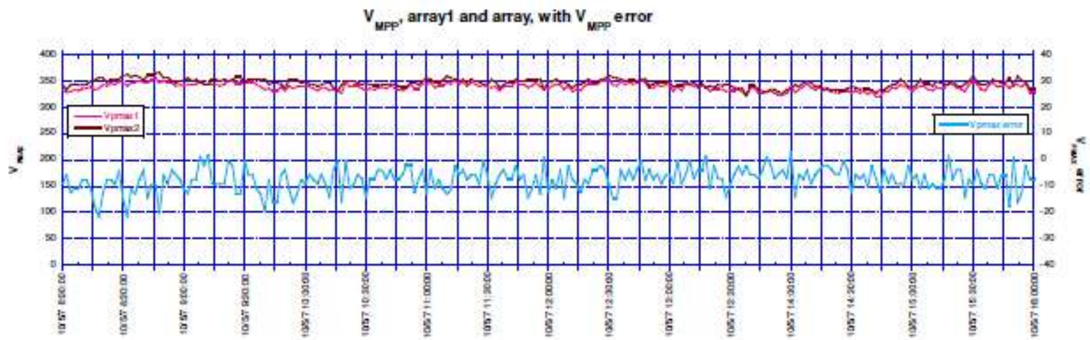
PVPowered
Simply More Reliable Solar

Array to Array Comparison
Micro-Amorphous

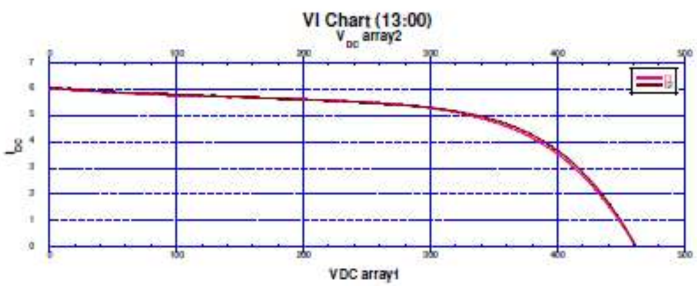
Test Conditions
May 7, 2010
8:00 to 16:00
2 minute increments

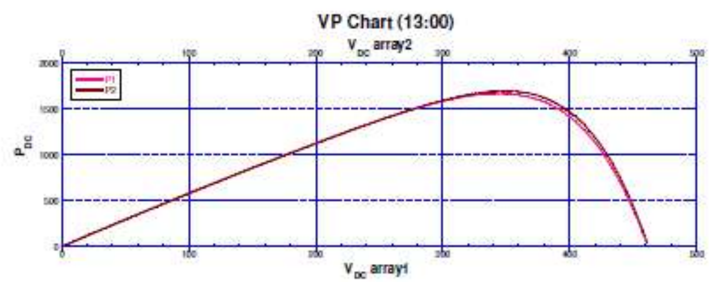


	Pmax error
Minimum	0.09
Maximum	92.96
Mean	17.32
RMS	23.32
Std Deviation	15.65
RMS error % of Pmax	1.34 %



	Vpmax error
Minimum	0.06
Maximum	21.65
Mean	7.59
RMS	8.77
Std Deviation	4.41
RMS error % of Vpmax	2.46 %

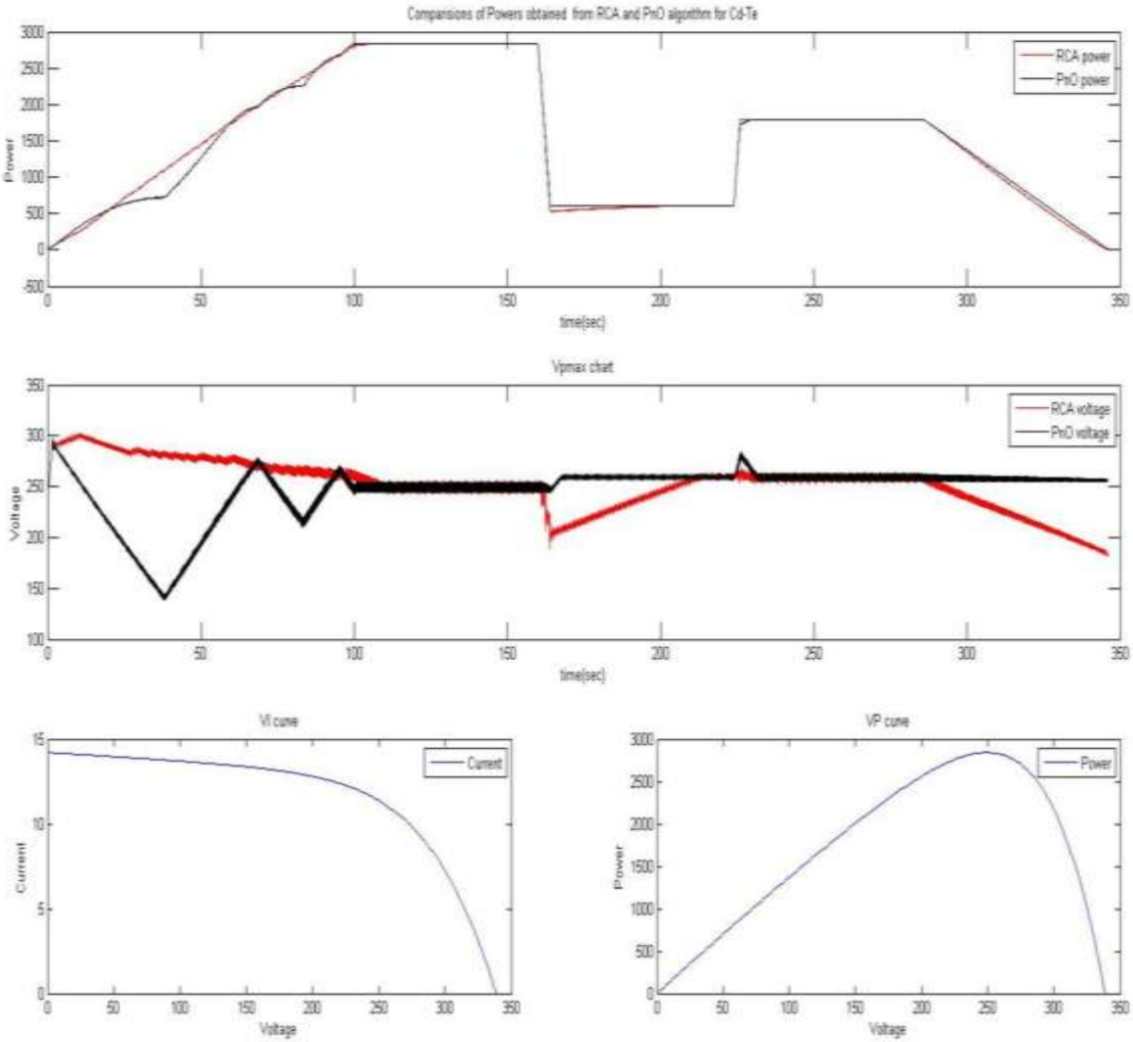




Portland General Electric

Laboratories

Simulation results: CdTe



	Pmax_err (RCA)	Pmax_err(P&O)
Minimum	0	0
Maximum	92.2914	365.9109
Mean	18.7933	28.8543
Median	9.6756	5.4195
RMS	26.4262	71.3915
Std. deviation	18.5784	65.3007

	Vpmax
Minimum	0
Maximum	145.0426
Mean	27.4154
Median	12.6932
RMS	42.7220
Std. deviation	32.7654

A new test protocol for maximum power point trackers

Michael Ropp, PhD, PE
President and Principal Engineer
Northern Plains Power Technologies

January 18, 2011

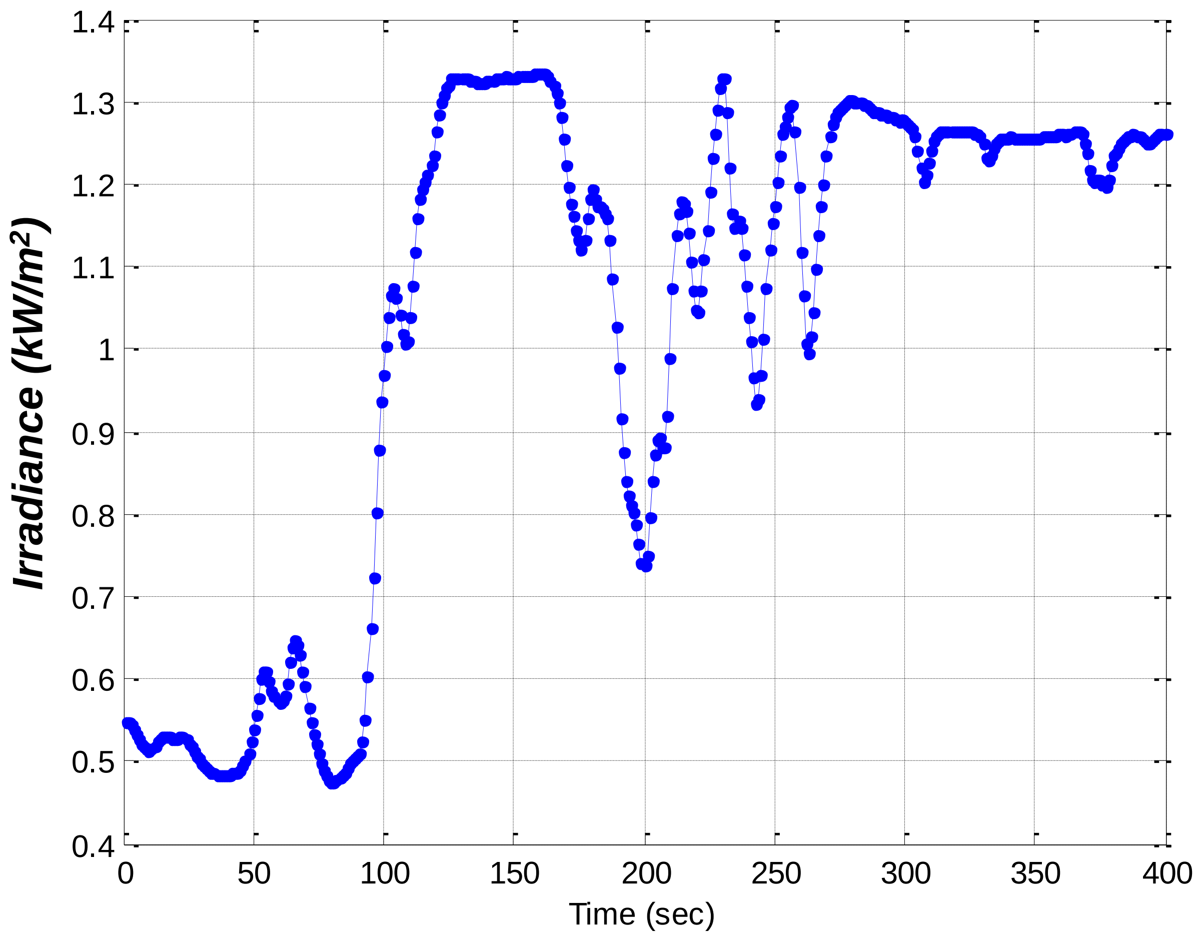
Motivation

- MPPT efficiency is a critically important part of the overall energy harvest equation

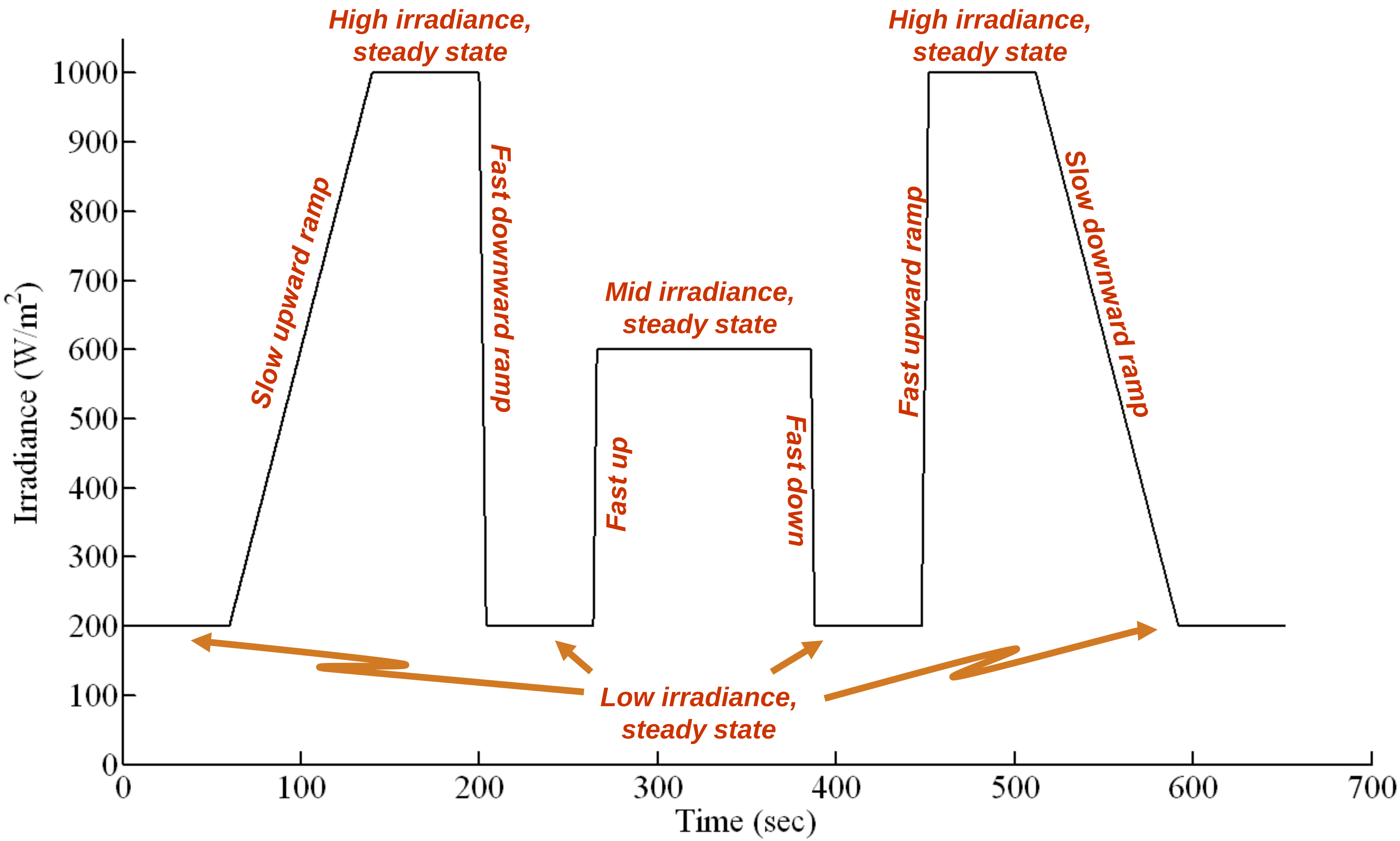
$$\eta_{MPPT} \equiv \frac{\int_0^T p_{PV}(\tau)\,d\tau}{\int_0^T p_{\max}(\tau)\,d\tau}$$

- MPPT test protocols exist, but they are somewhat cumbersome to use, and some require extensive field data sets
- Thus, there's a need for an MPPT test protocol that:
  - Is "realistic"
  - Is easy to perform and repeatable
  - Enables separate characterization of static and dynamic MPPT efficiencies
  - Produces values that are useful for
    - Comparing MPPTs against each other
    - Improving/tuning existing MPPT algorithms

The challenge for MPPT (track THIS...)



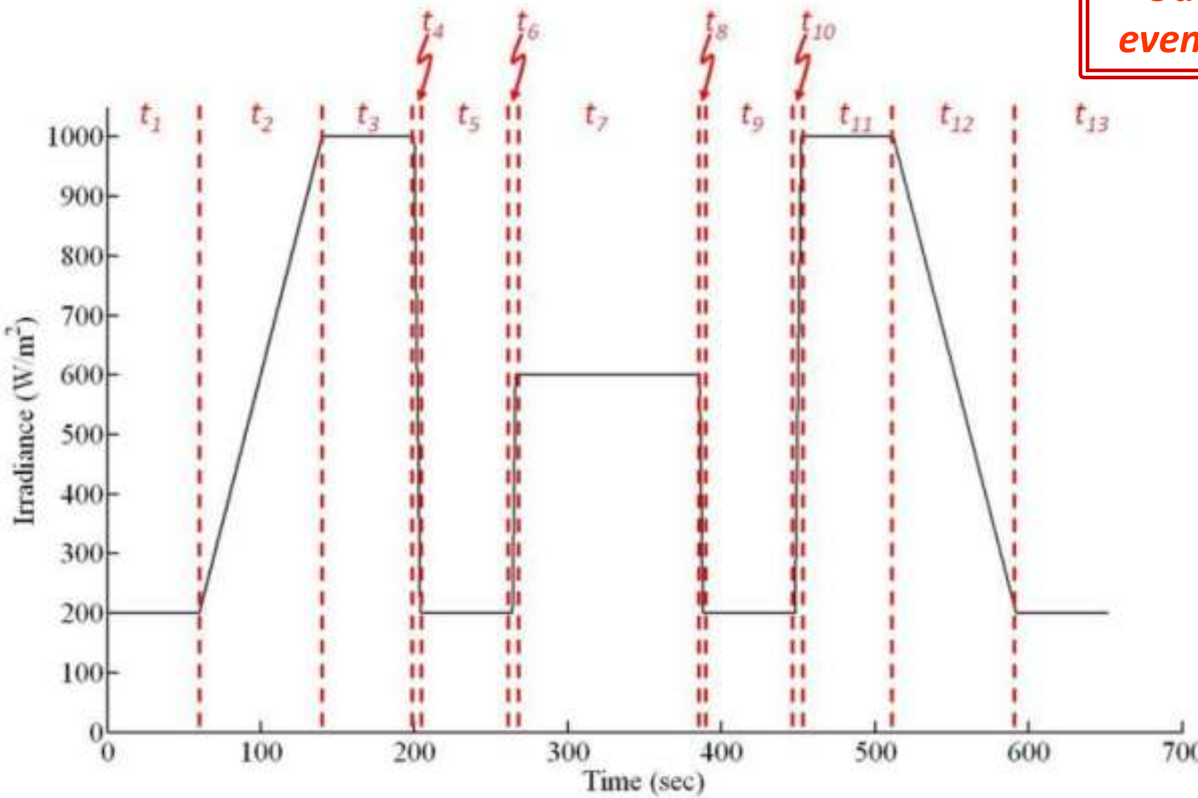
The proposed MPPT test protocol



Advanced features proposed by AE SEGIS team

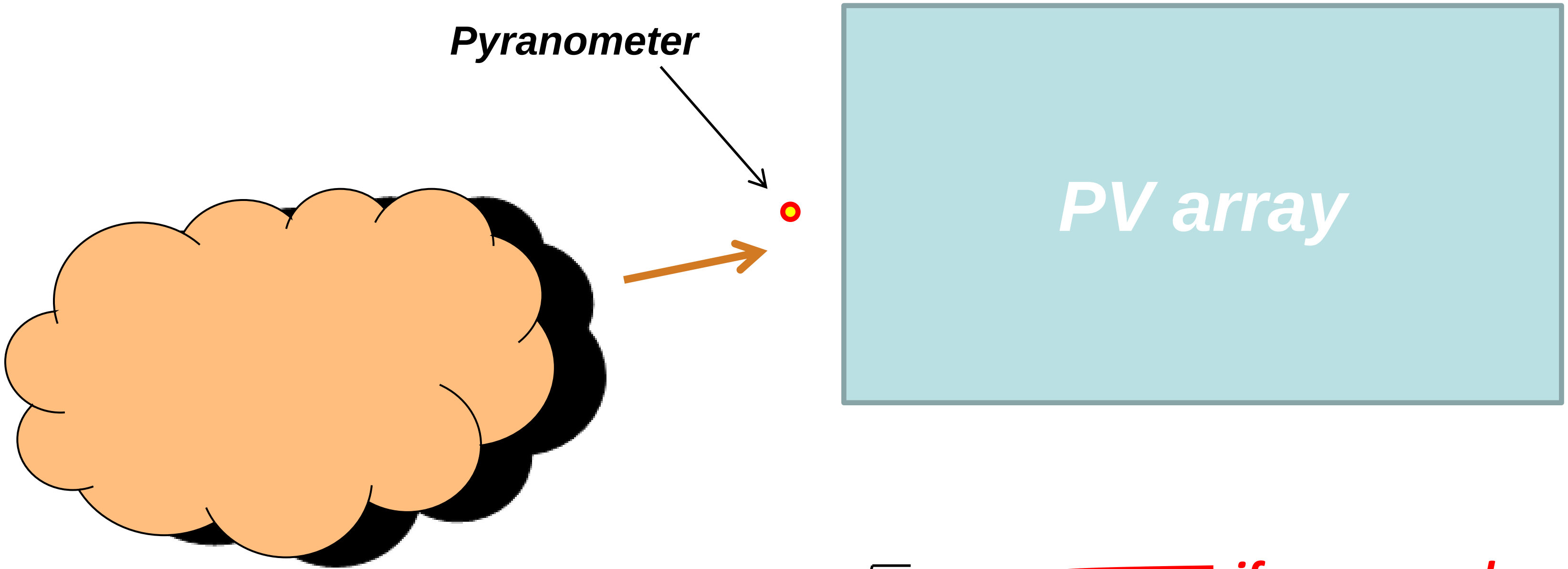
- Can separate static and dynamic parts of test protocol, and can also separate fast and slow dynamics

Odd t static; even t dynamic



Advanced features proposed by AE SEGIS team

- Proposed a means for adjusting ramp rates to account for different PV array sizes

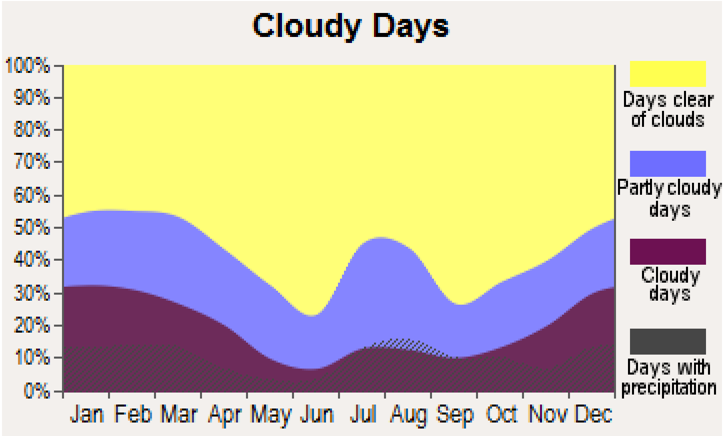


$$t = \frac{l}{v} = \frac{\sqrt{P}}{v\sqrt{G\eta_{PV}}}$$

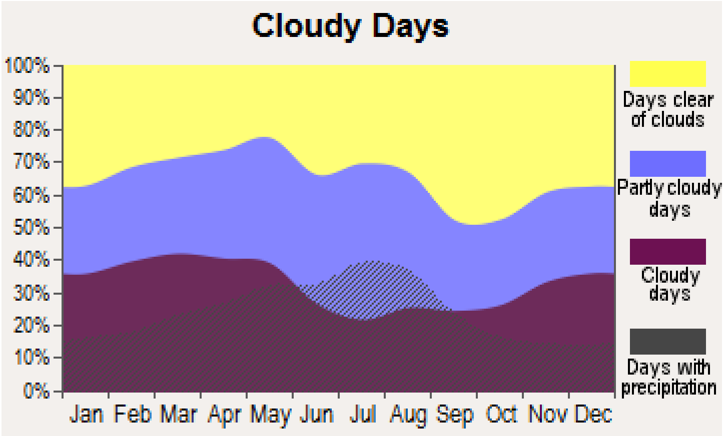
if array can be approximated as square

Published, and seeking industry feedback

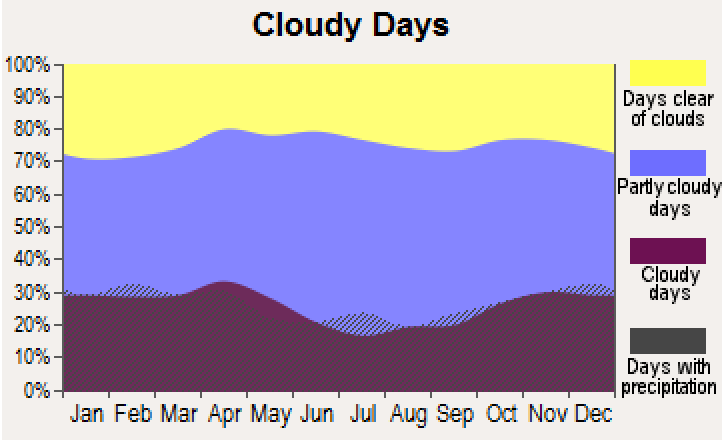
- This protocol was presented at the 37th IEEE Photovoltaic Specialists Conference, and published in the proceedings of that conference
- Actively seeking industry feedback
- One PV array simulator manufacturer has made this irradiance profile a standard feature of their simulator
- AE will lead by using this protocol to qualify its inverters in the future
- Next steps
    - Continual improvement
    - Industry acceptance



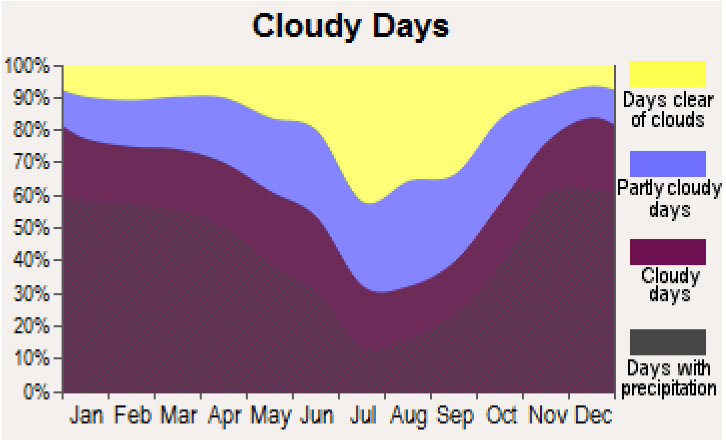
Phoenix, AZ



Denver, CO



Honolulu, HI



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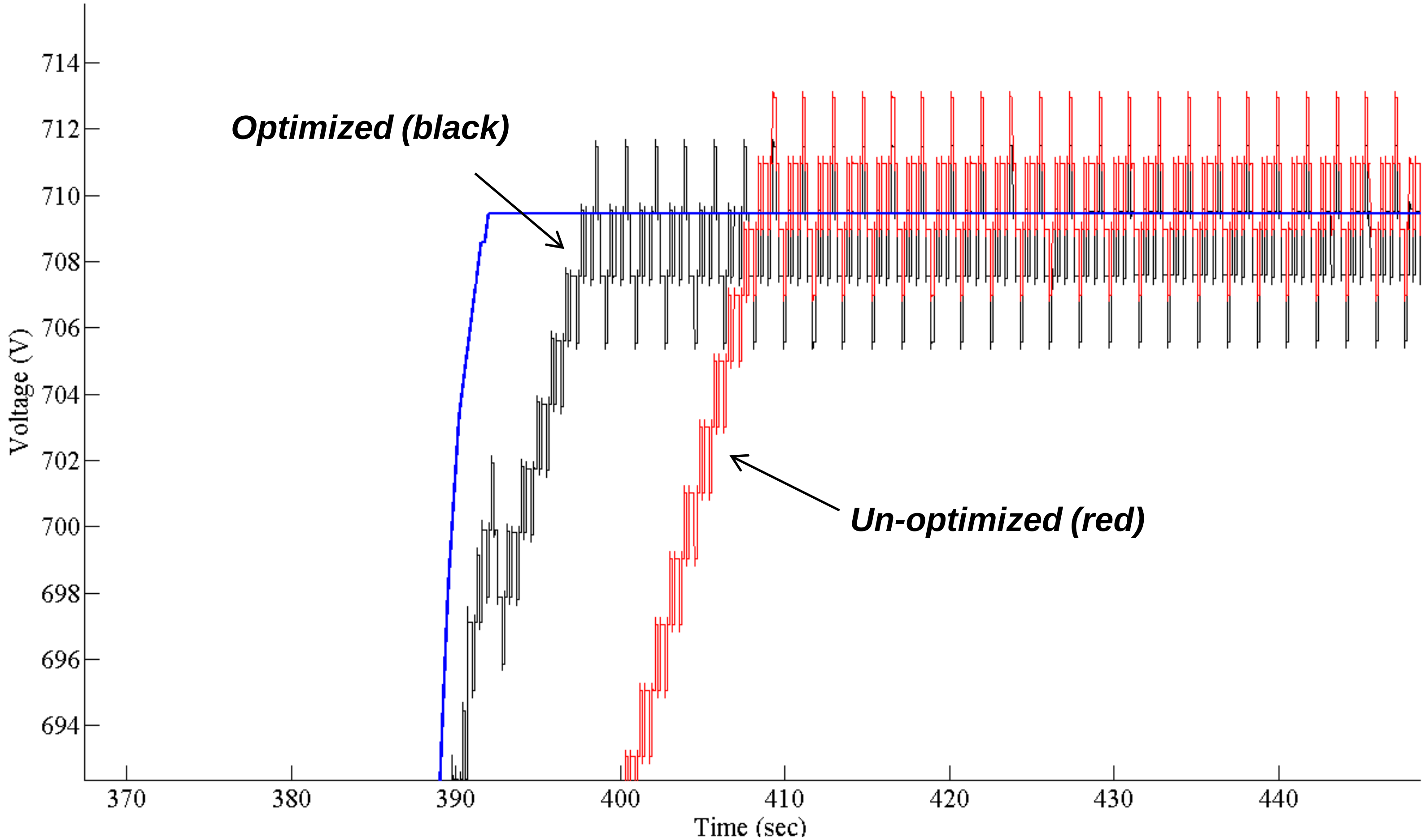
Maximum Power Point Tracking Tuning

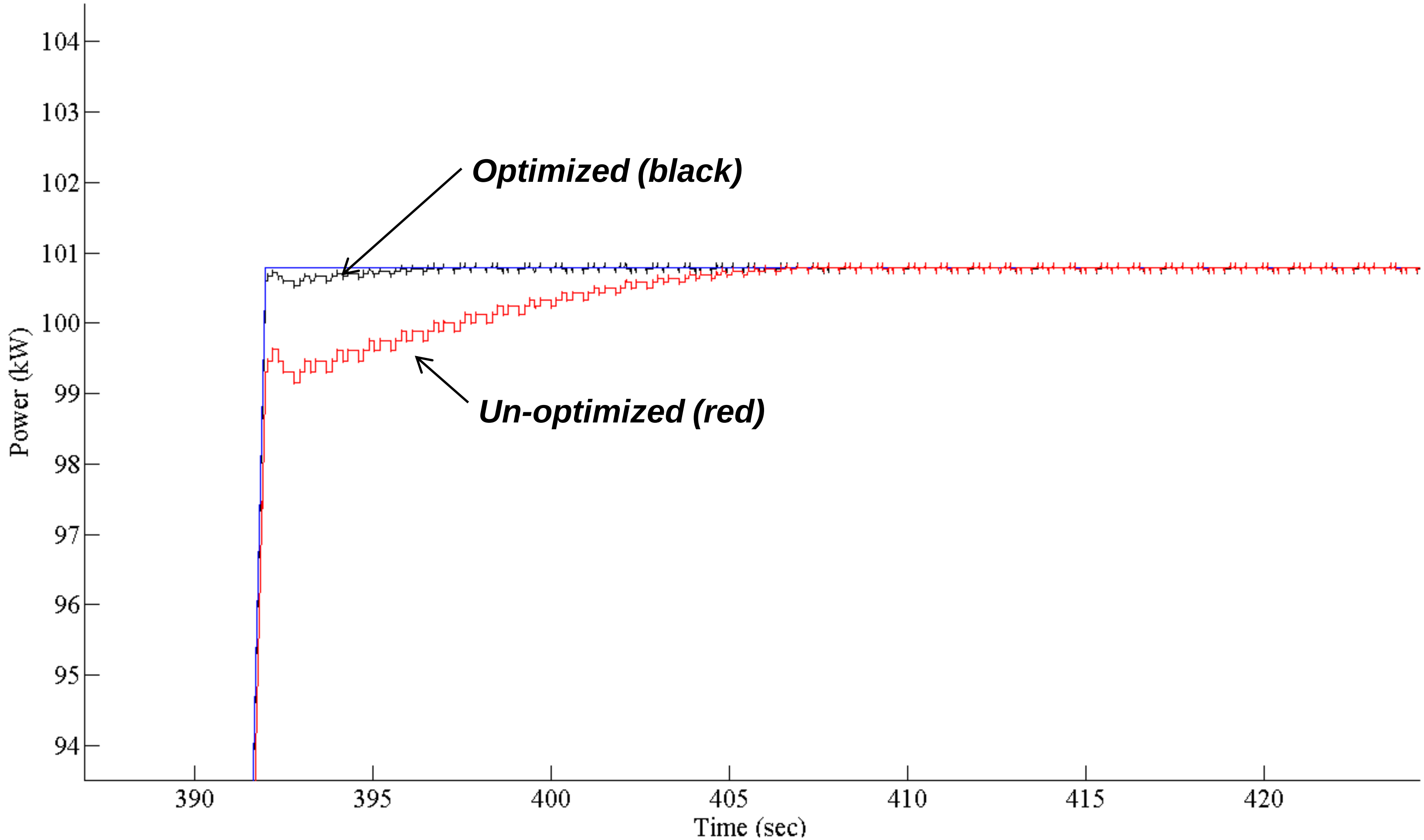
Steven Hummel
VP RD&E
Solar Power

January 18, 2011

Optimized Algorithm – Zoom-In on Voltage



Optimized Algorithm – Zoom-In on Power



Dynamic Tuning Example

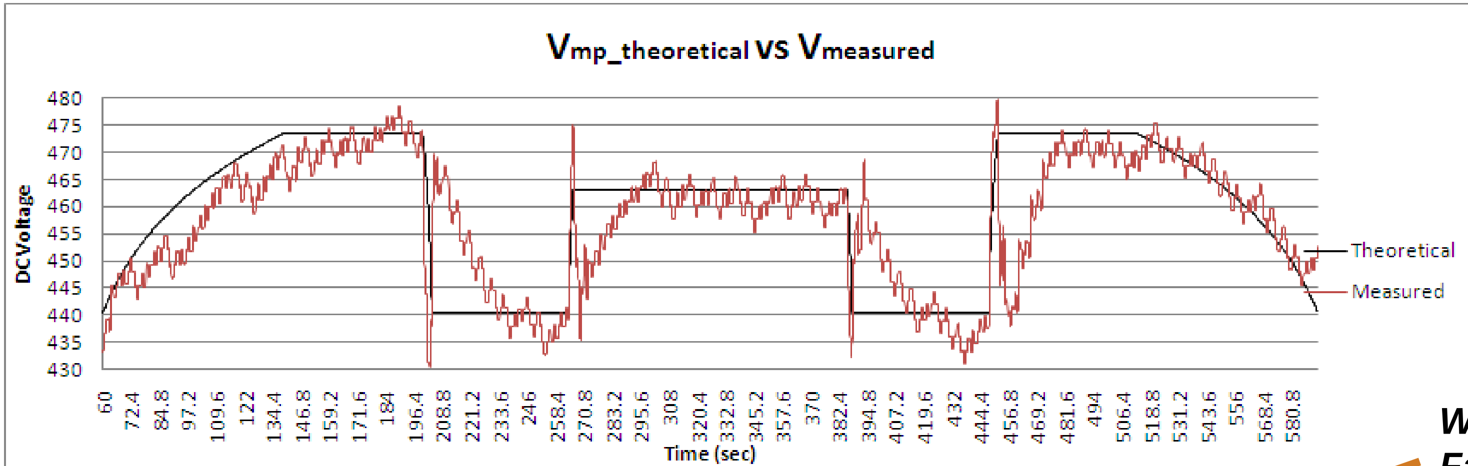


Figure 1. Voltage response

Windup Speed
Faster is better!

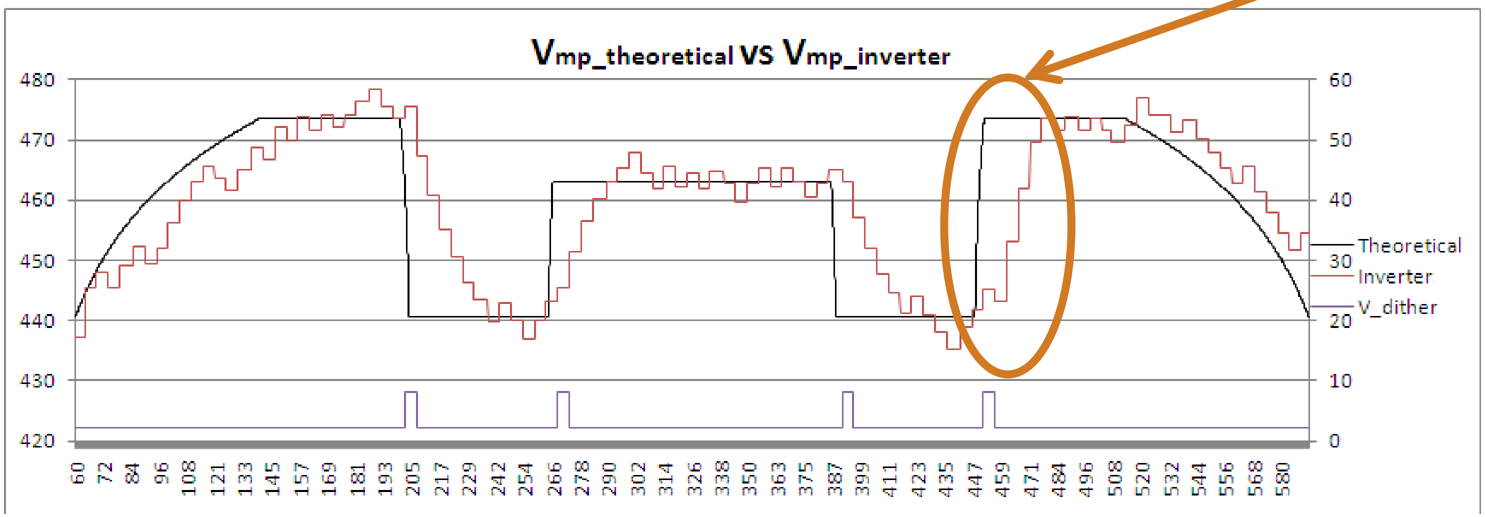


Figure 2. RCA performance

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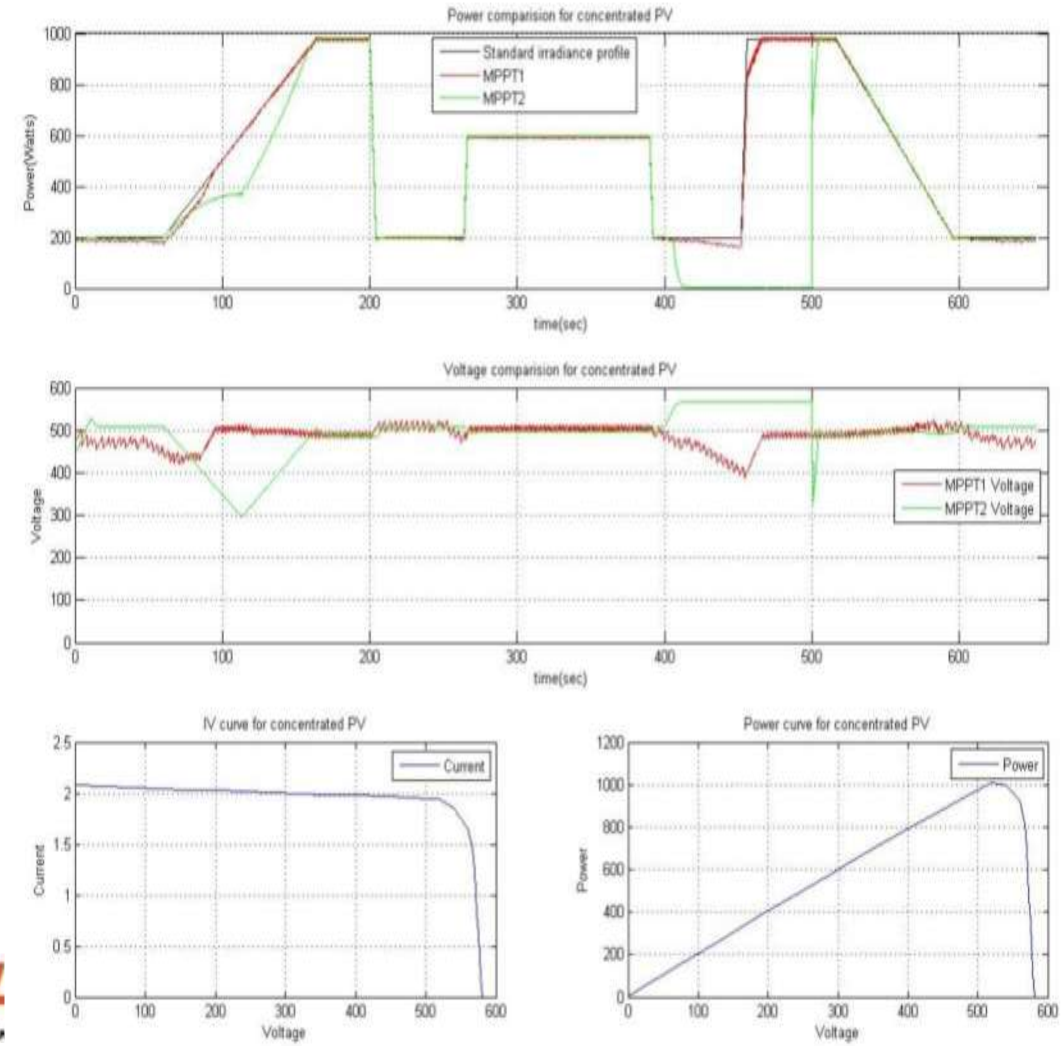
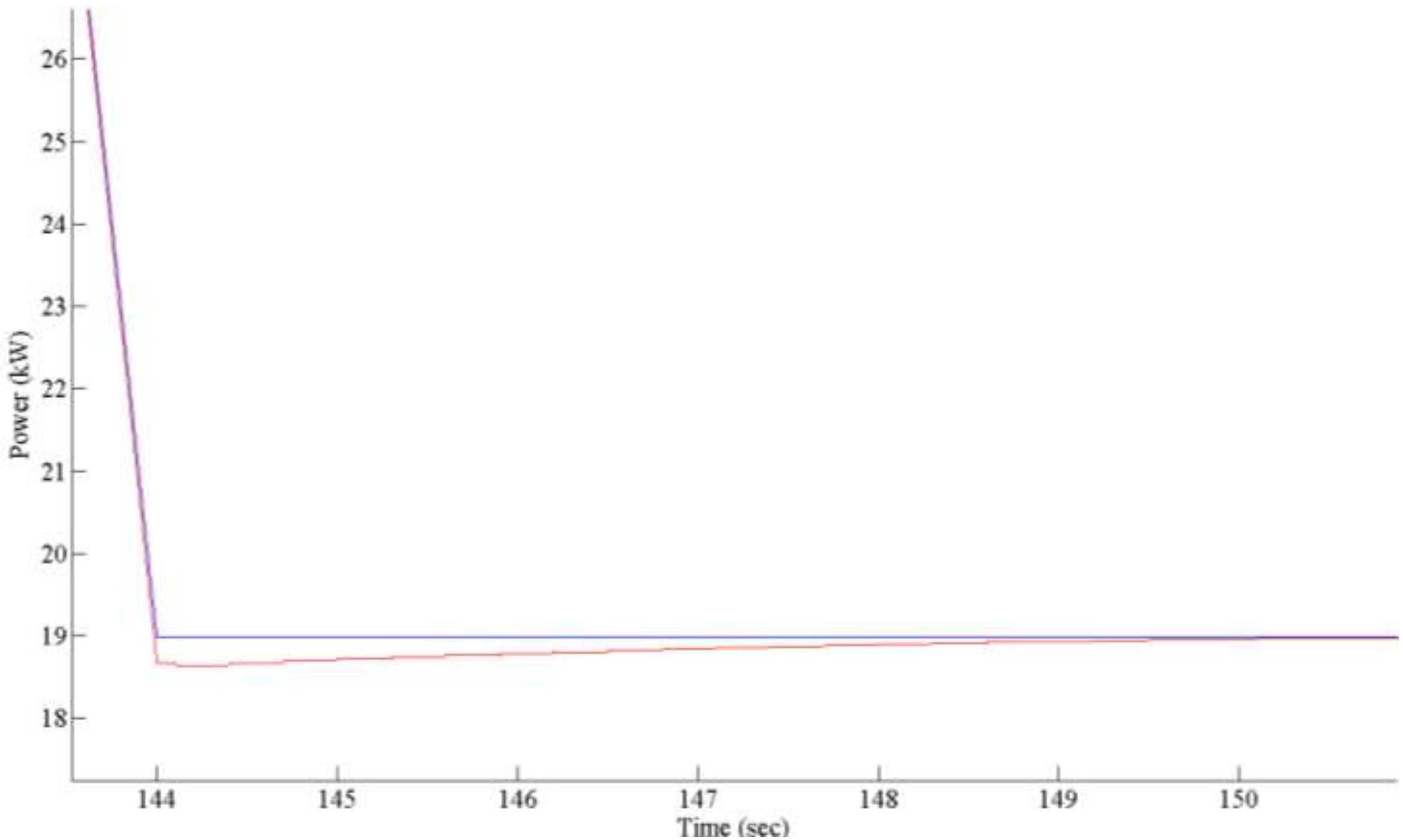
Usage example: two MPPTs tracking CPV



	V_{pmax} error
Minimum	0
Maximum	220.08
Mean	53.335
Median	42.62
RMS	70.39
Std. deviation	45.95

	MPPT1 power error (W)	MPPT2 power error (W)
Minimum	4.8325e-5	2.696e-6
Maximum	198.9753	977.8437
Mean	8.8015	113.653
Median	3.9254	4.9924
RMS	17.67	257.3087
Std. deviation	15.323	230.8481

Quantifying Lost Harvest Energy



$$E_{hl} = \int_0^T \left(p_{max}(\tau) - p_{pv}(\tau) \right) d\tau$$

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Take-Aways

- A proposed dynamic MPPT test protocol has been created, presented to the industry for feedback, and is being used to develop and quantify AE's inverter products
- An MPPT test bed has been created that includes solar simulation and under-sun testing of multiple solar module families
- It has been demonstrated that MPPT parameter tuning helps maximize energy harvest across module technology families
- A tunable MPPT algorithm has been developed and patented which demonstrates high performance under both static and dynamic irradiance conditions.
- The granted patent includes tuning inputs from weather and solar forecast inputs

Agenda: Morning Presentations

- **9:00-10:00: Utility Interactive Controls**
  - Michael Mills-Price, SEGIS Program Manager, AE Solar Energy
- **10:00-10:15: Break**
- **10:15-11:15: Maximum Power Point Tracking (MPPT): The other half of the energy harvest equation**
  - Michael Ropp, Principal Engineer, Northern Plains Power Technologies
  - Steve Hummel, VP of Engineering, AE Solar Energy
- **11:15-12:15: Synchrophasor-based Island Detection: Solving a critical gap in utility integration under high penetration PV**
  - Mesa Scharf, Director of Solutions Engineering, AE Solar Energy
  - Michael Ropp, Principal Engineer, Northern Plains Power Technologies
  - Michael Mills-Price, SEGIS Program Manager, AE Solar Energy
- **12:15-1:15: Lunch**

Synchrophasor-based island detection: Solving a critical gap in utility integration under high penetration

Mesa Scharf
Director, Solutions Engineering
AE Solar Energy

Michael Mills-Price, PE
SEGIS Program Manager
AE Solar Energy

Michael Ropp, PhD, PE
President & Principal Engineer
NPPT

September 20, 2011

High Penetration Exists Today

- PV Industry experiencing year on year explosive growth
  - 40% historical growth, 42% annual growth expected through 2020 *
  - More states incenting solar, grid parity within reach
- High PV penetration on the US grid is here
  - Clustering of PV installations causing utility challenges today
- Utilities with clustering of PV are beginning to flag and deny interconnect applications (ex: New Jersey, Hawaii and Oregon sites)
  - Utilities and the PV industry are learning in real time
  - Interconnect standard (IEEE1547) does not work for high penetration
  - Inverter technology and standards must evolve to support grid integration challenges

**Multiple sources, EPIA, Bloomberg New Energy Finance*

Effects on Grid Stability Under High Penetration of PV

PV Behavior	Effect on Grid	Mitigation
Intermittency due to cloud transients	• Poor voltage regulation	• VAR/PF support • Controlled ramp rate • Storage, forecasting
Inverters tripping offline (IEEE1547)	• Poor voltage regulation • Lack of grid support	• Low voltage ride through • Extended trip parameters
Increased local generation to load ratios	• Low power factor load from generator perspective • Poor voltage regulation	• Scheduled or fixed PF/VAR • Autonomous voltage regulation
Unintentional islanding	• Equipment damage • Safety hazard	• Transfer/trip • Power line carrier • Synchrophasor island detection

Most mitigations require updated UL1741/IEEE1547 standard or behind the fence operation to be enabled as well as market drivers

PV Interconnects in Transition

Function	Low Penetration (IEEE1547)	High Penetration
Voltage regulation	Not permitted	Critical to operations
Power factor	Typically 1.0	± 0.90 adjustable
Protection	Integrated anti-islanding	Transfer-trip
Voltage and frequency tolerance	50% voltage for 160 mS	Zero volt 3-phase fault for 150 mS
Remote control	Monitoring only	SCADA interaction

Standards and Req'ts Definition

- EPRI communications standard
- IEEE1547.8 development
- CAISO standard
- German medium voltage directive

Business Models

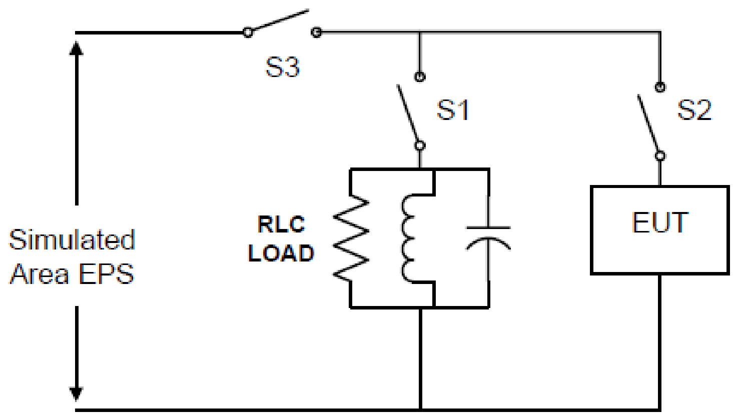
- Financial incentives needed to drive adoption of advanced features
- Value of real vs. reactive power
- Load, time of use, weather

Unintentional Islanding – What, Why & How

- What is a power island?

3.1.11 island: A condition in which a portion of an Area EPS is energized solely by one or more Local EPSs through the associated PCCs while that portion of the Area EPS is electrically separated from the rest of the Area EPS.

  - Unintentional islanding – an unplanned island
- Why consider island detection?
  - Safety
  - Power quality - equipment damage / utility liability
- How do we prevent unintentional islanding?
  - Voltage and frequency trip points
  - Inverter-based anti-islanding
  - By design – Generation / load ratios
  - Transfer-trip
  - New techniques



Source: IEEE1547 & IEEE1547.1

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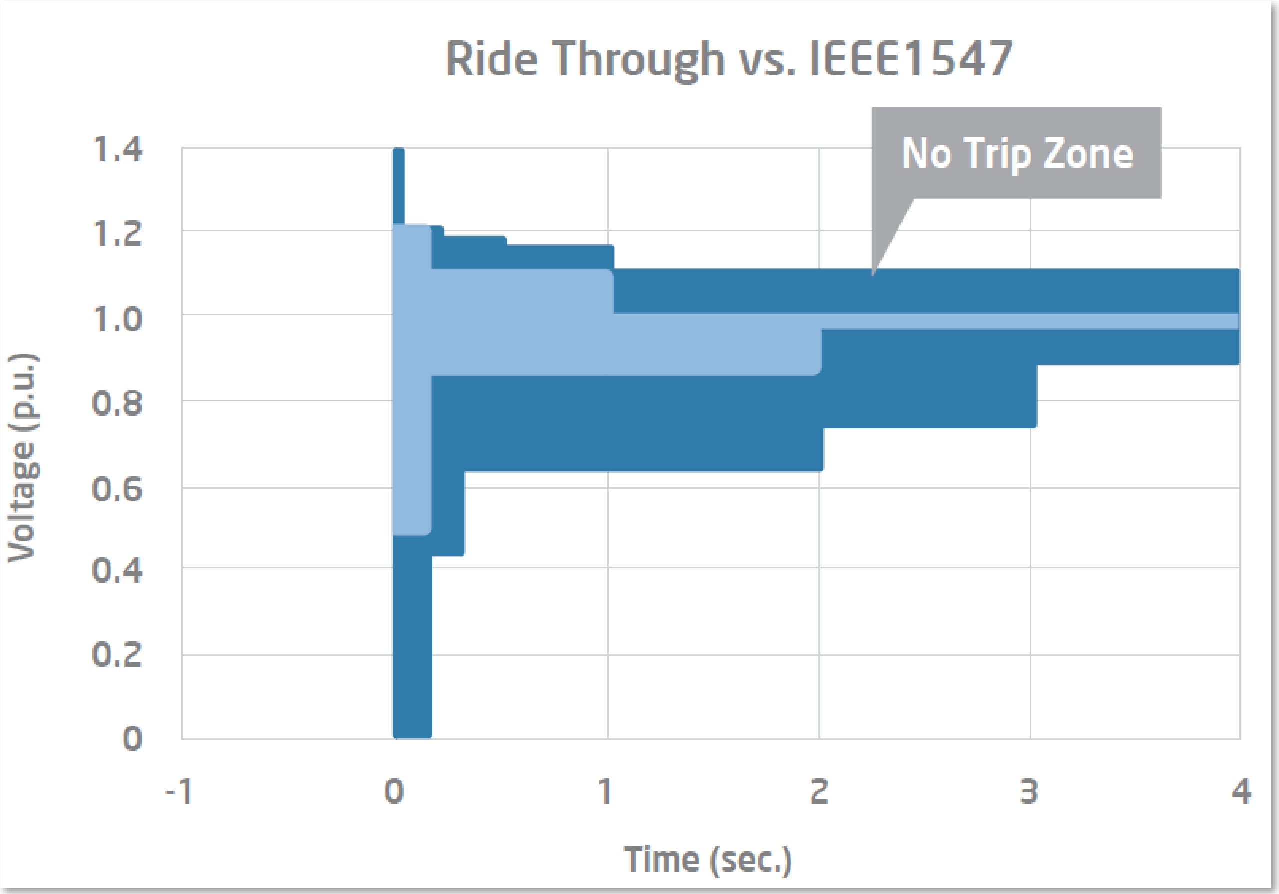
Why do we need a new anti-islanding technique?

- Existing inverter-based island detection works well in low penetration cases
- Existing approach – 'perturb and observe' algorithm
  - Power quality issues
  - Negative impact on system stability
  - Loss of effectiveness under very high penetration
- Need to enable ***grid support functions***
  - Today's active islanding detection works by creating an abnormal voltage
  - Utilities want PV to help correct abnormal voltages—critical for high penetration
  - Can't do both!
- Primary alternative is transfer/trip
  - Works well for transmission connected PV (e.g. > 10MW)
  - Costly and inflexible for distribution connected PV
- ***A new approach is needed***

Supporting the Grid
Knowing to Ride Through vs. Disconnect

- IEEE1547
  - Disconnect if voltage or frequency is out of range
  - Destabilizing at high penetration level
- Alternate utility protection approaches will be required to enable ride through



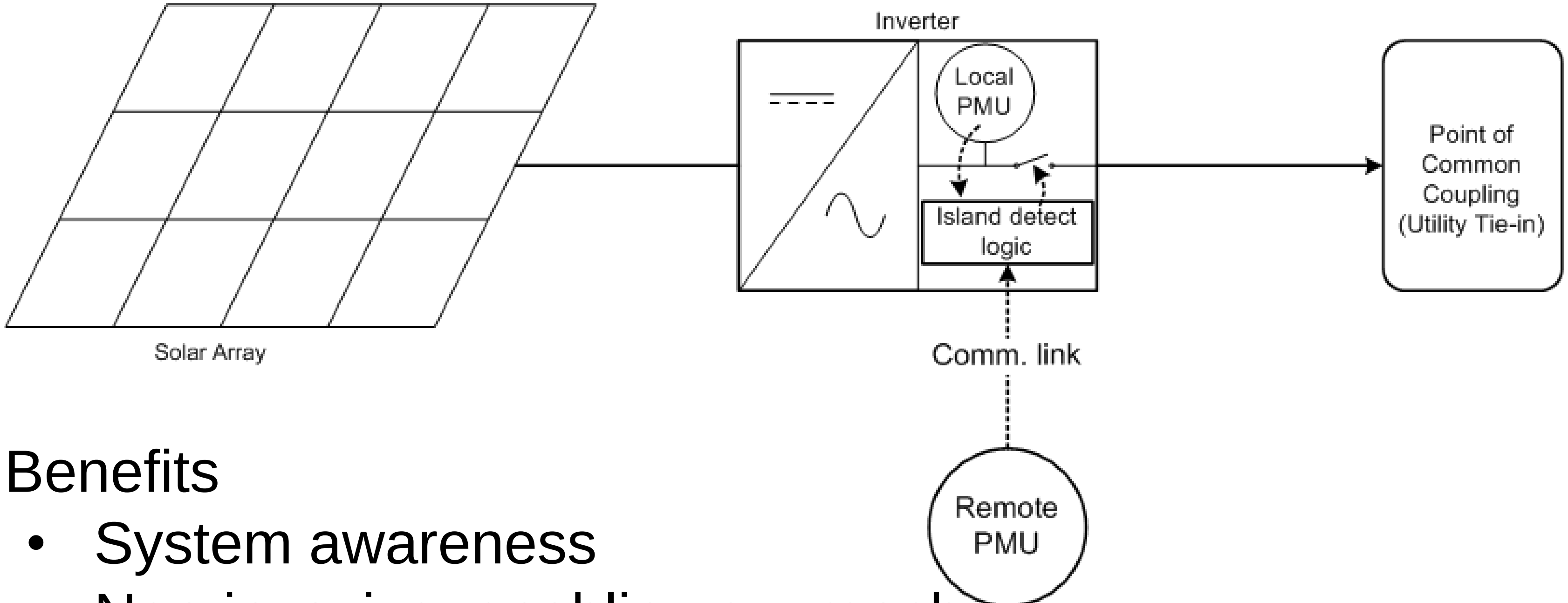
PV generation becomes integral to utility planning and operations as PV penetration increases

Island Detection Alternatives

Technique	Safety	Power Quality	Advanced features	Infrastructure Needs	Cost
SFS, other P&O methods	Good	Poor	Static VAr support	None	$
PLC	Very good	No effect	VAr support LVRT	Power line carrier signal Modeling of system impedance	$$$
Transfer-Trip	Very good	No effect	VAr support LVRT	Fiber comm, Relay / breaker for disconnect Known feeder config	$$$$
Synchro-phasor based detection	Very good	Improves / very good	Dynamic adaptive VAr support, micro-grid, synchronized reclosure, LVRT, Enables smart feeder operation	PMU data Comm. channel Local PMU device	$$

Grid Protection and System Awareness: Synchrophasor-Based Island Detection

- Why synchrophasors? - a new application
- How does it work?



- Benefits
  - System awareness
  - Non-invasive, enabling approach
  - Leverages existing utility investments
  - Enables advanced utility support capability

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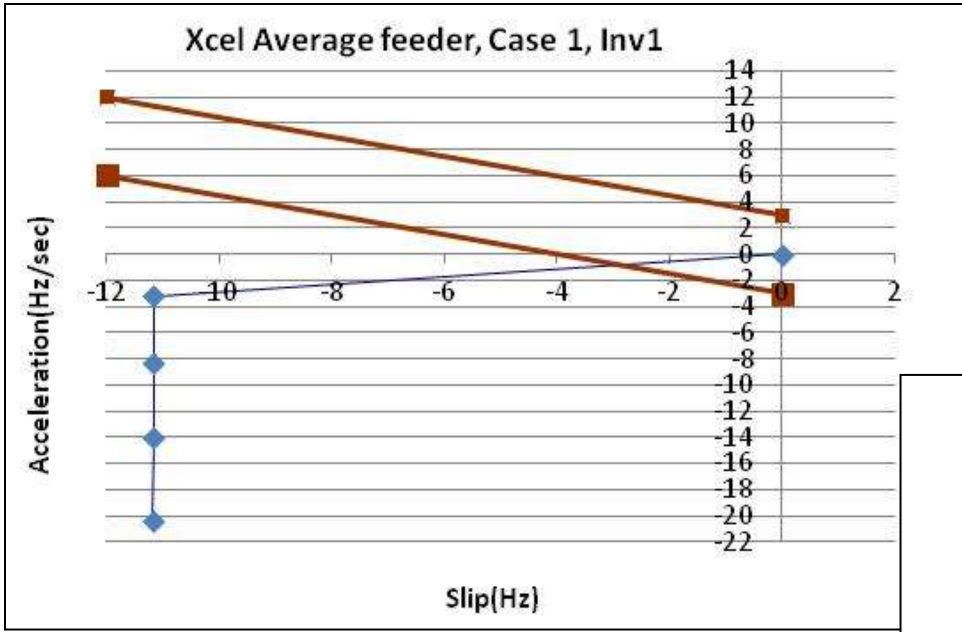
Local processing algorithms

- Wide Area Network (WAN) method
  - Developed by SEL
  - Uses relationships between phasor parameters
  - During SEGIS Stages 1 and 2, extensively investigated for distribution applications
  - Found to work very well in nearly all cases
    - Usually VERY fast
    - Some issues seen when rotating machines were included in the island
- Correlation Coefficient Based (CCB) method
  - Developed by NPPT under SEGIS program
  - Uses statistical relationships between reference and local synchrophasors
  - Thoroughly investigated by AE SEGIS team
  - So far, looks extremely promising
    - Very good at detecting islands with no false trips
    - Time-to-trip can be more variable than one would like

Testing to date (both algorithms)

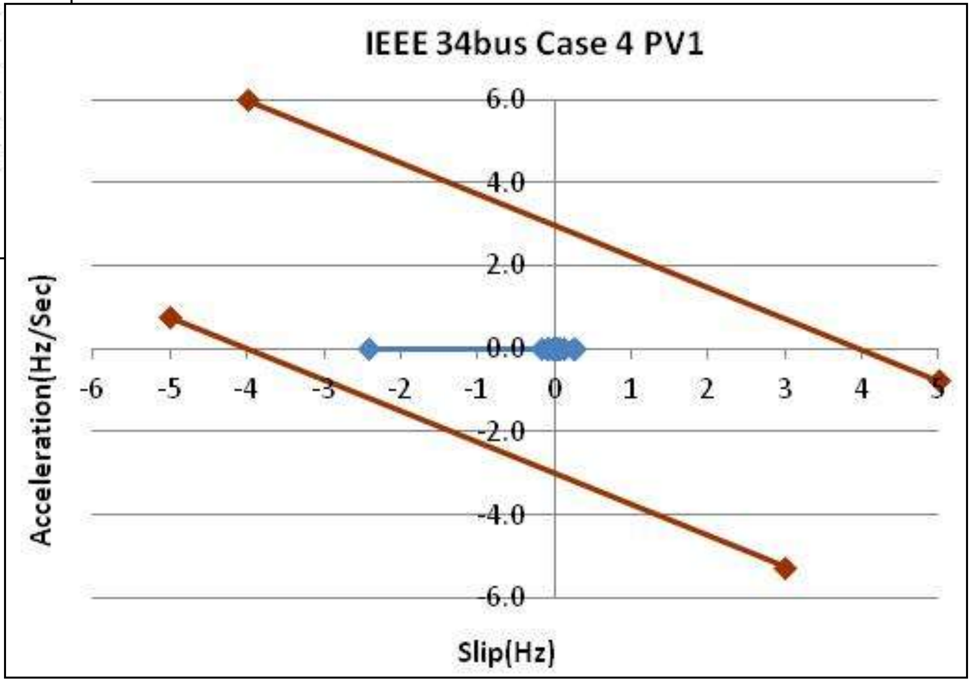
- Simulation
  - Over a dozen feeders, including IEEE-34 and 37 and many real-world feeders
  - Four scenarios
    - Multi-inverter
    - Multi-inverter plus engine-genset
    - “Italian blackout”
    - Local switching event
- Hardware-in-the-loop testing using synthesized, simulated, and measured field data
- Laboratory testing
  - Extensive lab testing in Bend
  - Initial testing in the DETL at Sandia
- Field testing
  - ODOT feeder testing in Stage 2 using fiber
  - WAN has been field-deployed

Results to date—WAN in simulation



Simulated multi-inverter island test case—detected in less than 40 msec

Ride-through case (large motor switching event)—successfully rides through



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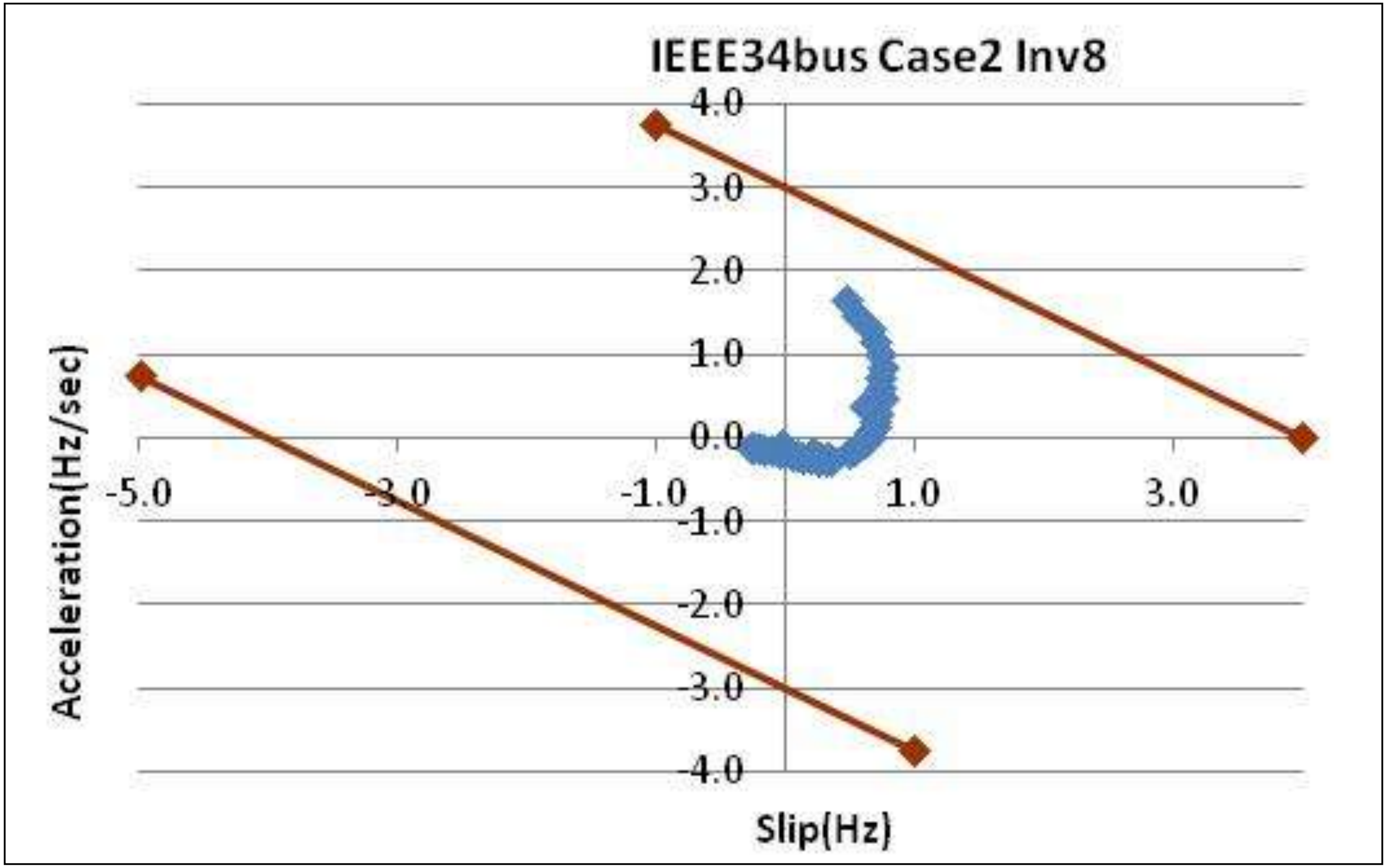
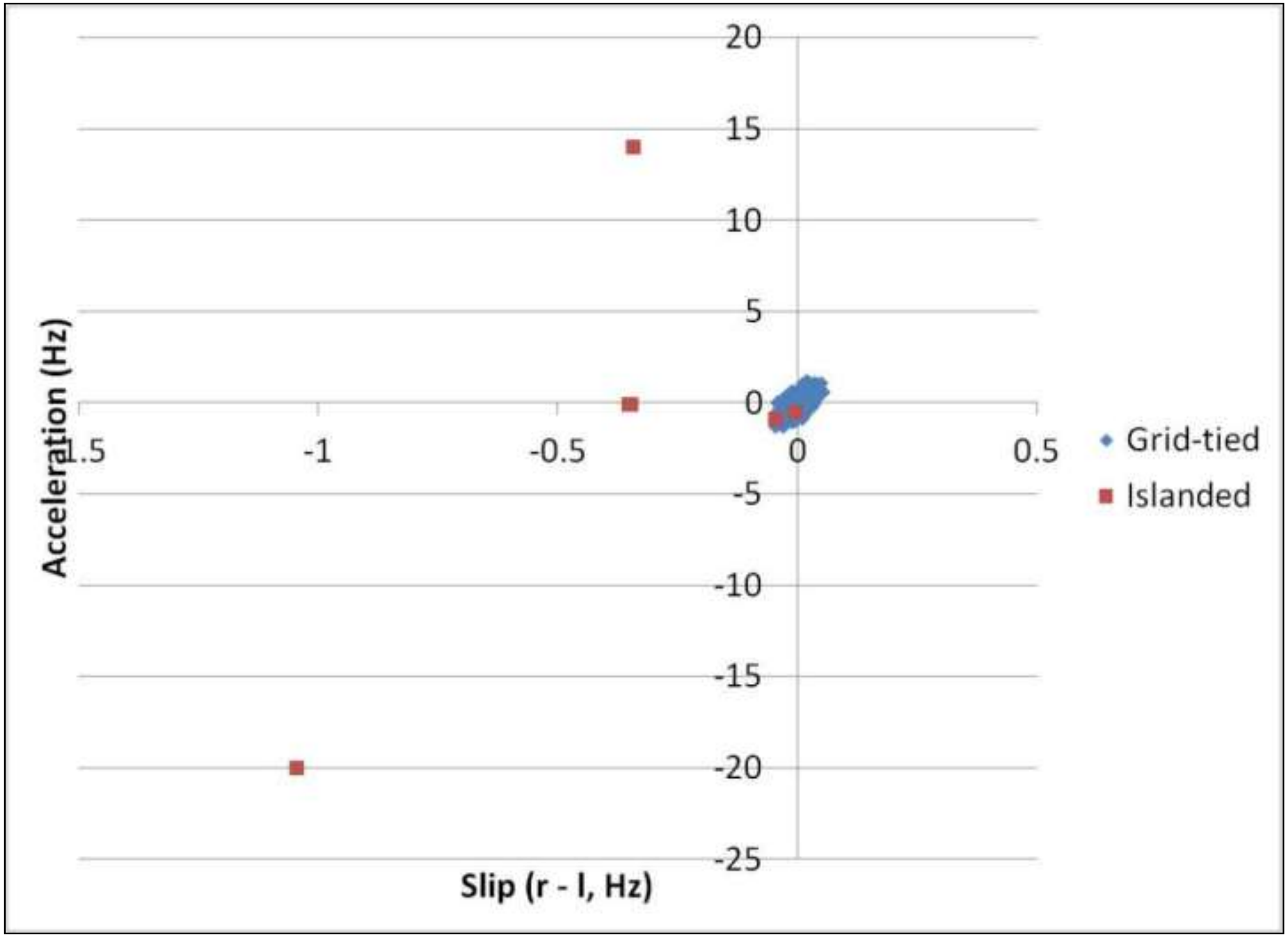
Results to date—WAN in simulation

One of the WAN problem cases: island event on IEEE 34-bus feeder with inverters + engine-genset



Results to date—WAN in the field

Measured results from island test on Hemlock-Mason feeder; island is detected on 3rd message (about 60 msec)



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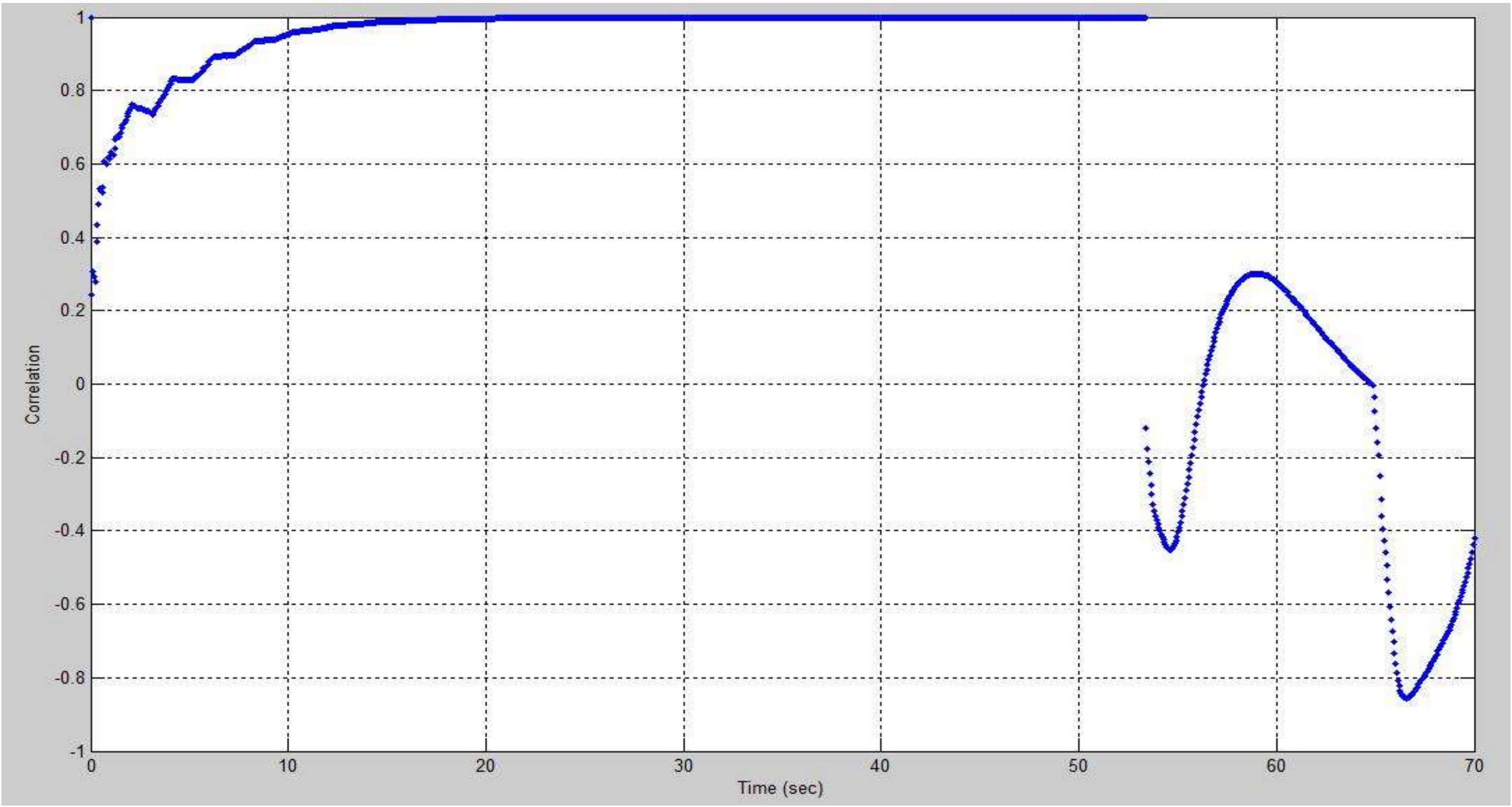
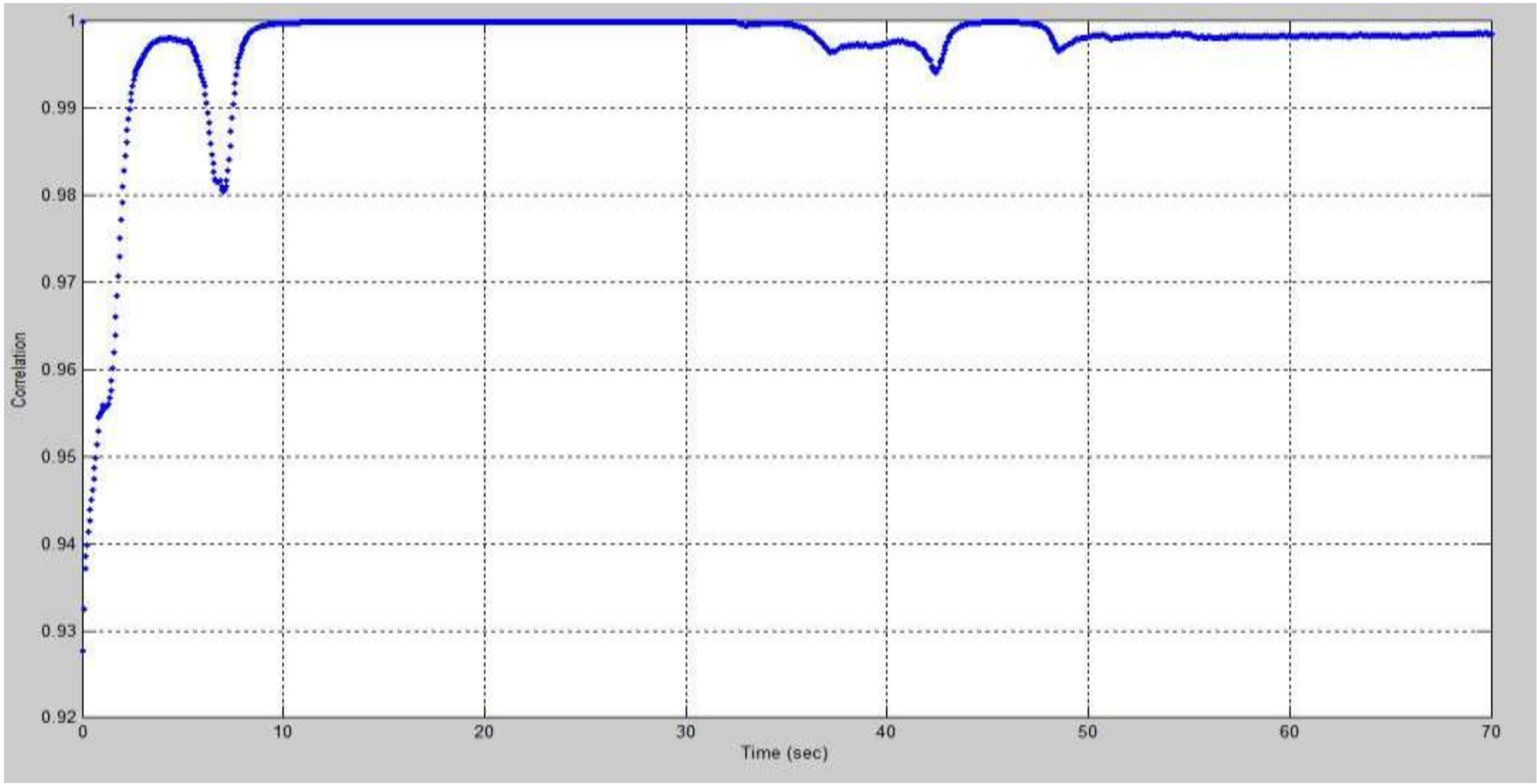
Results to date—CCB in simulation



CCB on IEEE 34-bus feeder with engine-genset, N = 80; detection in < 200 msec

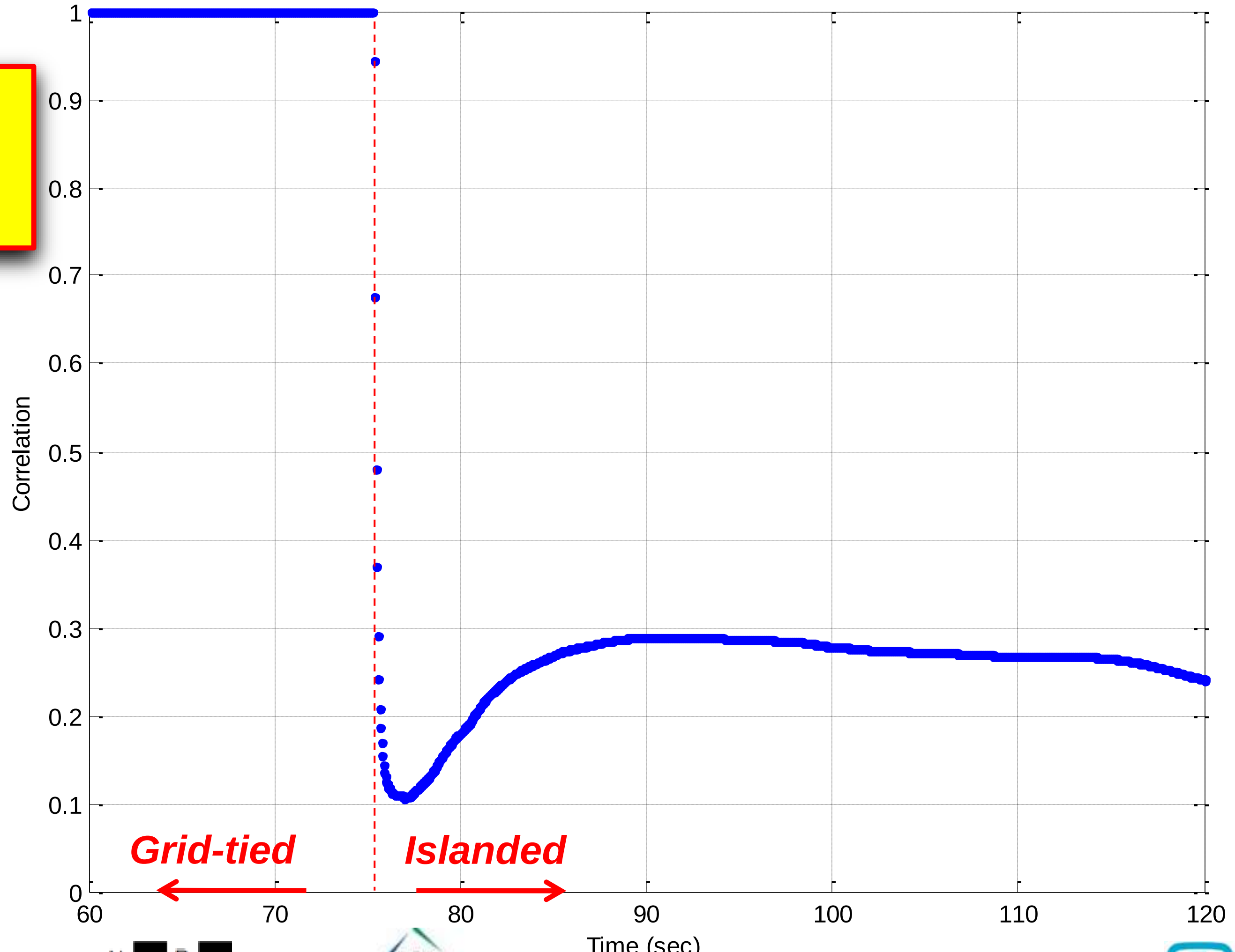
Results to date—CCB in simulation



CCB on IEEE 34-bus feeder in Italian Blackout case, N = 80; rides through as desired

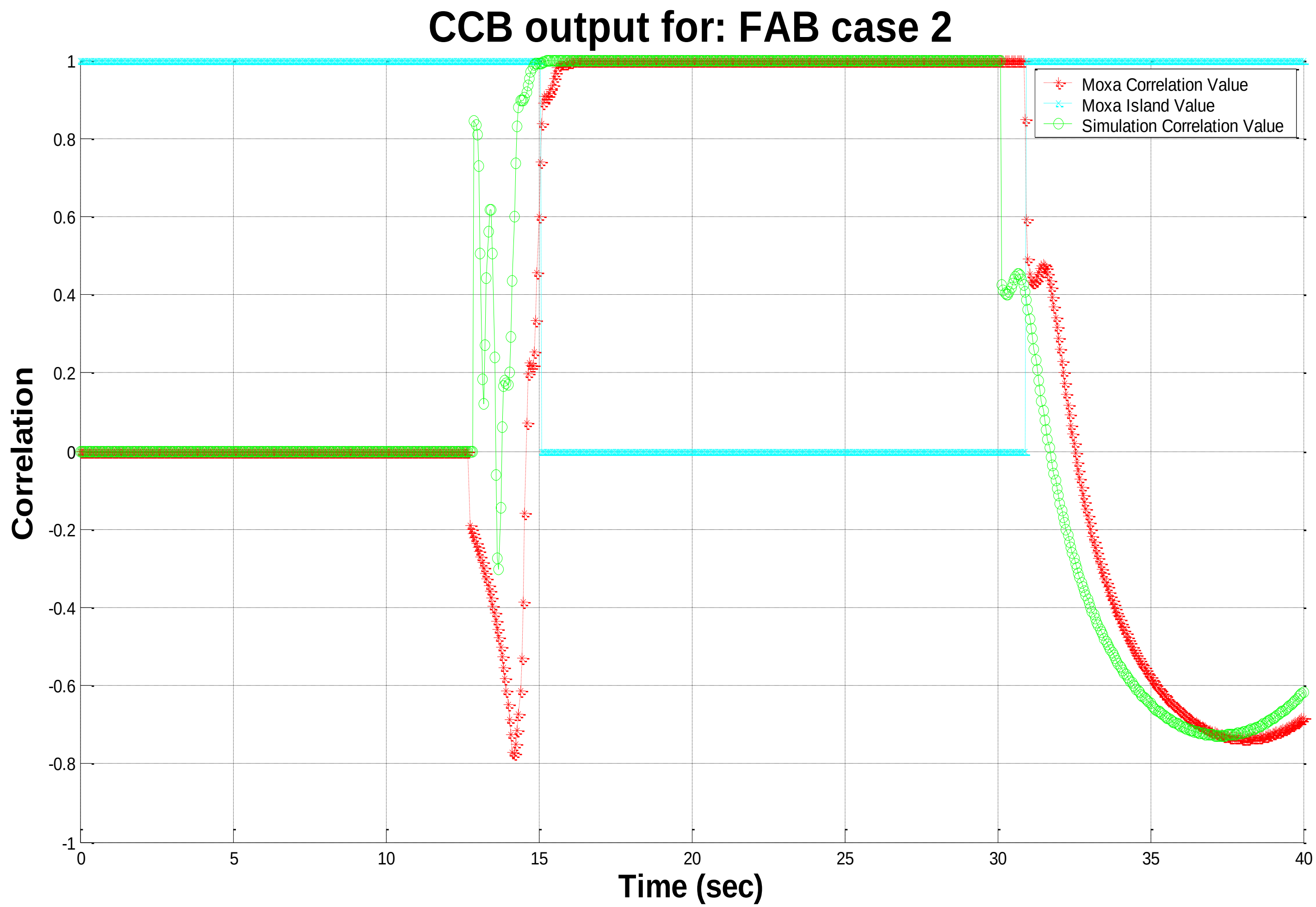
Results to date—CCB in the lab (Bend)

Pearson's
N = 2400
f_s = 20 Hz



Results to date—CCB in the lab (Brookings)

Comparison of simulated and hardware-in-the-loop results for a model of a real-world weak distribution feeder



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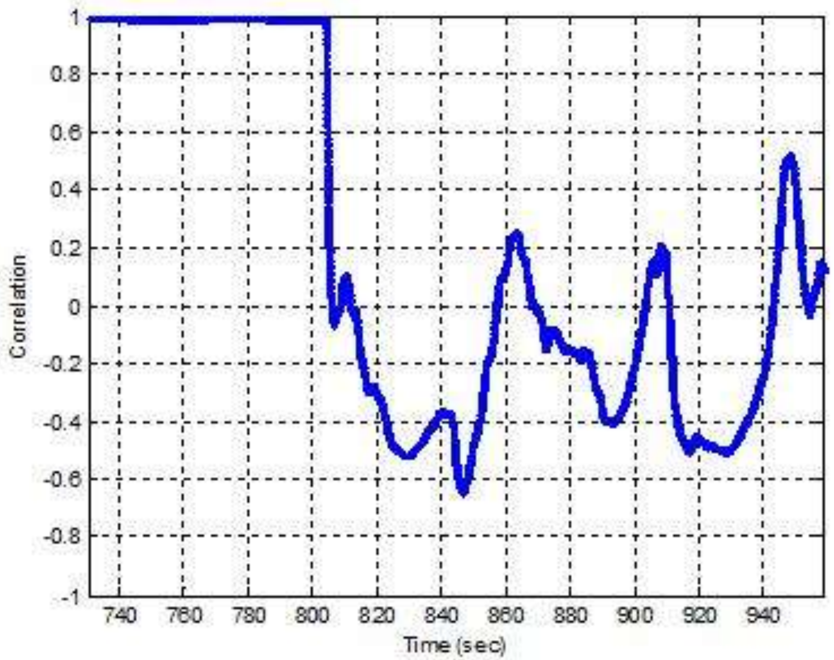
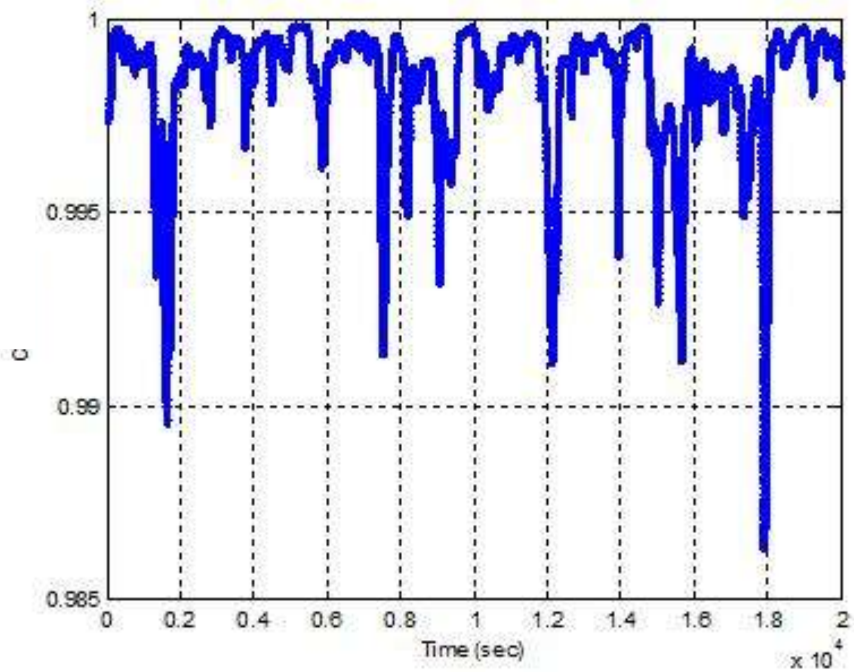
Results to date—CCB in the field (Tualatin)



ODOT feeder live island test—detected in less than 300 msec

Results during period of no island test and normal load variation—rides through as expected



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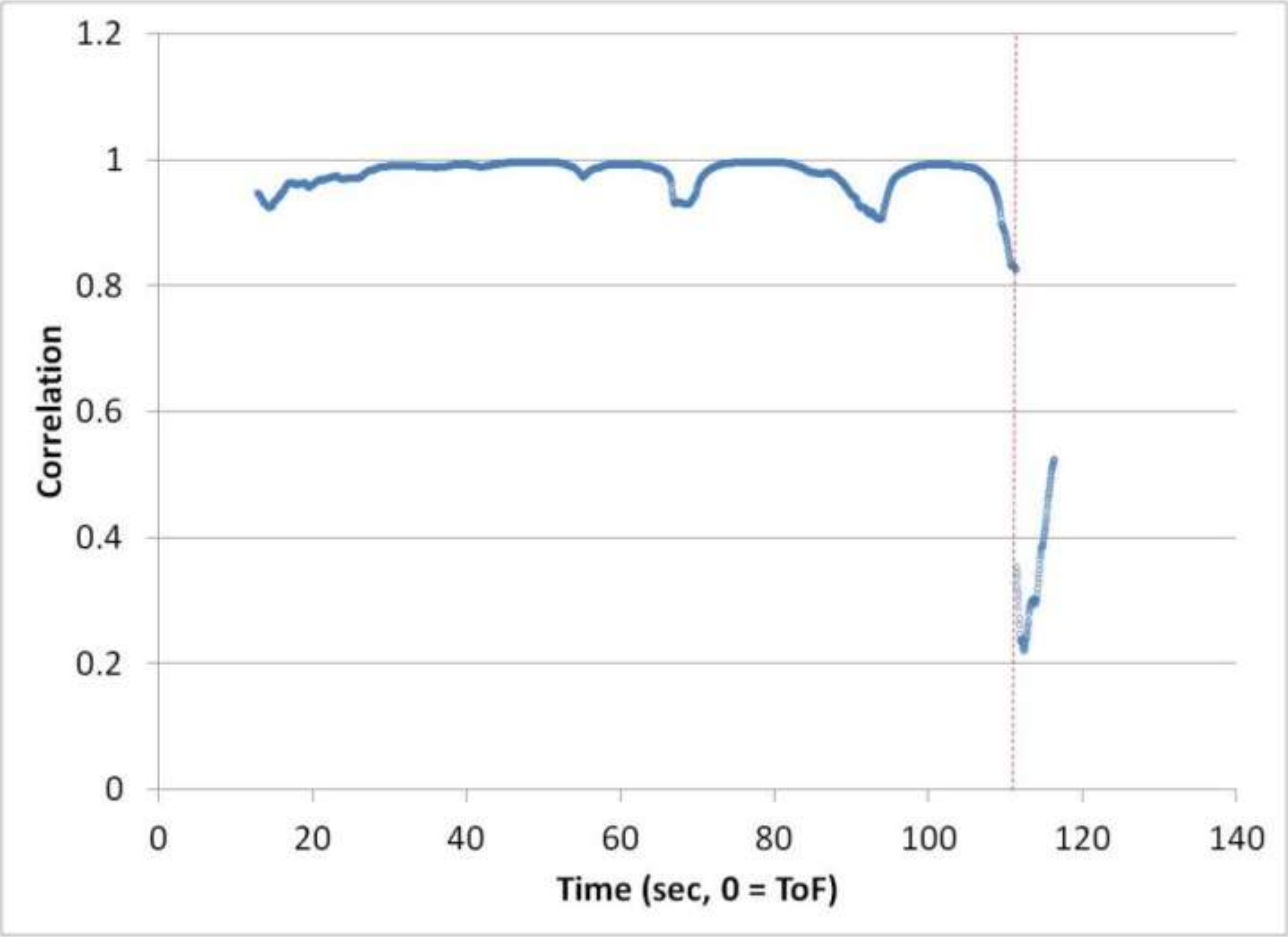
Results to date—CCB in the field (Hemlock)



Learning and concerns

- WAN
  - Highly effective in most cases
  - Tends to trip faster than CCB
  - Can sometimes have trouble in cases with engine-gensets
  - Unclear whether it would pass the IEEE 1547 test because that test is at zero slip/accel
  - Bottom line: very promising, further improvements possible
- CCB
  - Detected islands in all cases tested, and rode through all ride-through cases
  - Theoretically, should never fail to detect an island
  - Can be slow to respond
  - Bottom line: exceedingly promising, further improvements possible
- Note that WAN and CCB could easily be used together
- ***Synchrophasor-based island detection clearly works***

Synchrophasor Island Detection Progress to Date

SEGIS

Stage 1 - Concept

- Need identified
- Approach identified

SEGIS

Stage 2 - Feasibility

- CCB invented & lab tested
- ODOT demo
  - WAN technique
  - Fiber

SEGIS

Stage 3 - Prototype

- CCB inverter integrated
- Extensive model validation
- Radio link to Sub
- Threshold / disconnect

What's Next

SEGIS-AC – Field Test

- Integration into SEL H/W
- Field validation
- Productization
- Standards adoption

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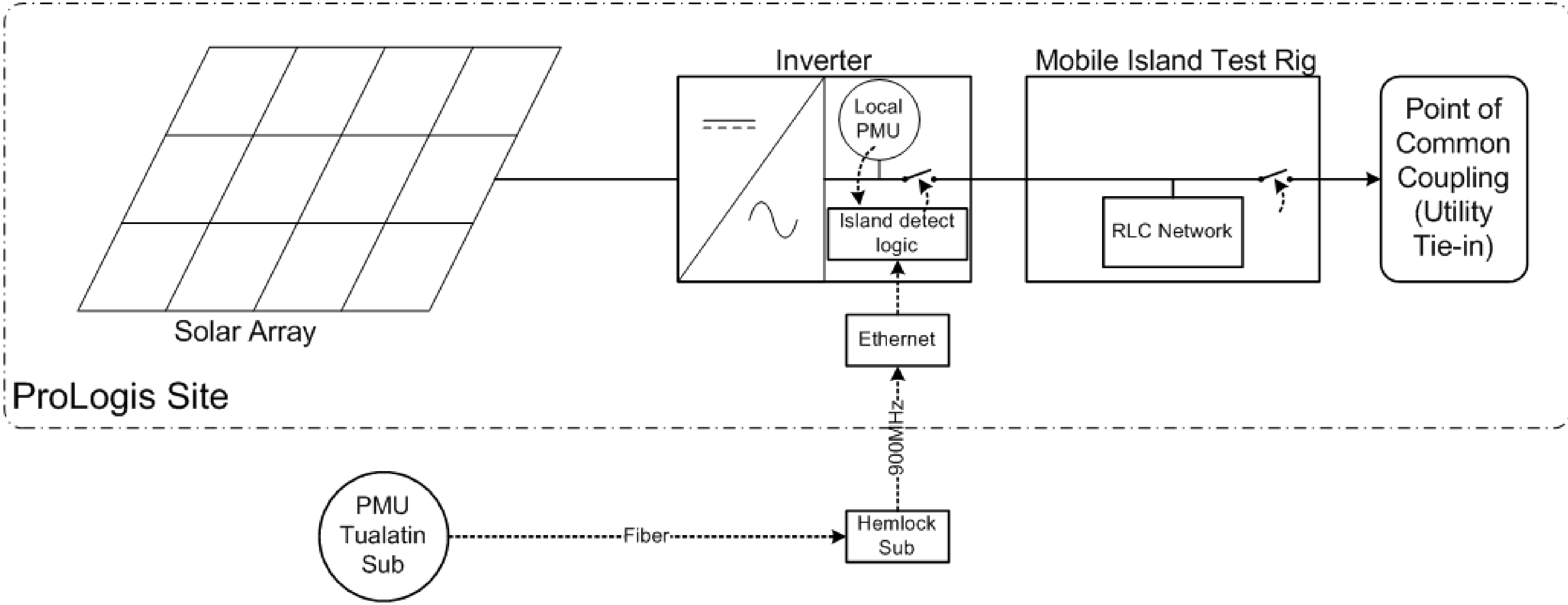
Demonstration Today
Synchrophasor Island Detection



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The Prologis Site
Park #1: Demonstration Site

- 418,176 Watts
- Unisolar Array
  - 2904 Modules
  - 264 x 11 PVL144 Modules
- PVP260kW (demo)
- PVP100kW

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Remote Synchrophasor Reference Tie-in

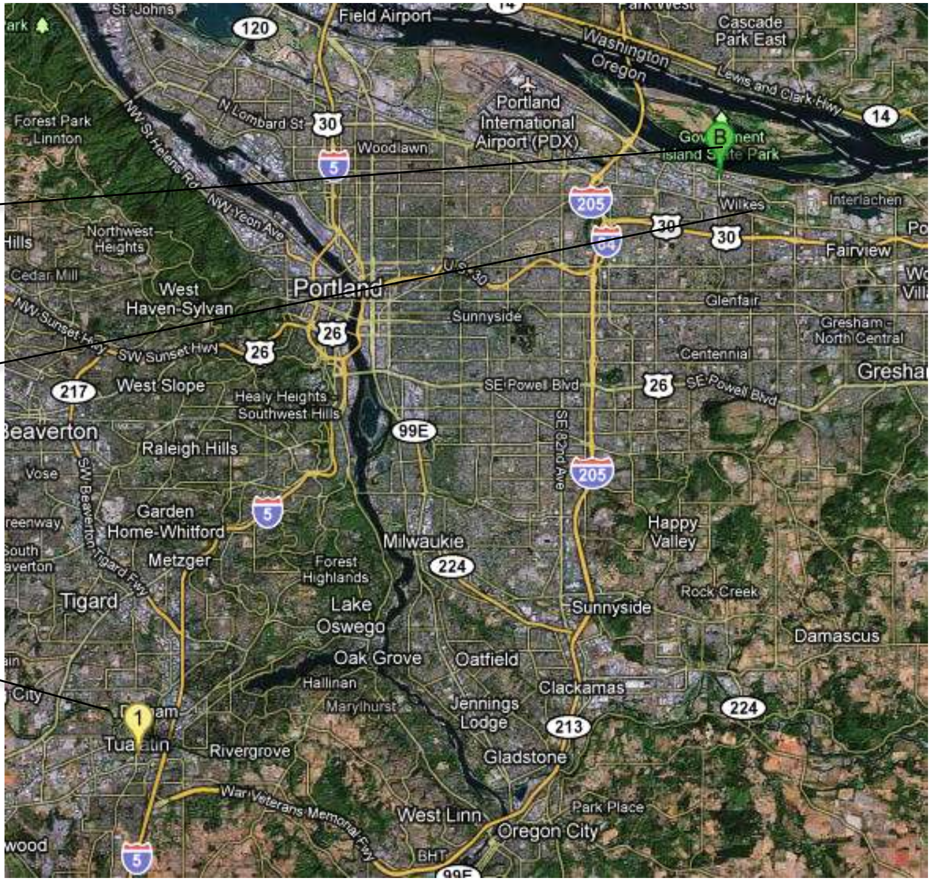
- 900 MHz Radio link to Hemlock feeder
- Fiber link to Tualatin substation

Prologis Solar Site

Hemlock Feeder

Tualatin Substation

Remote PMU Reference



Wireless Link to Hemlock Substation

Hemlock feeder

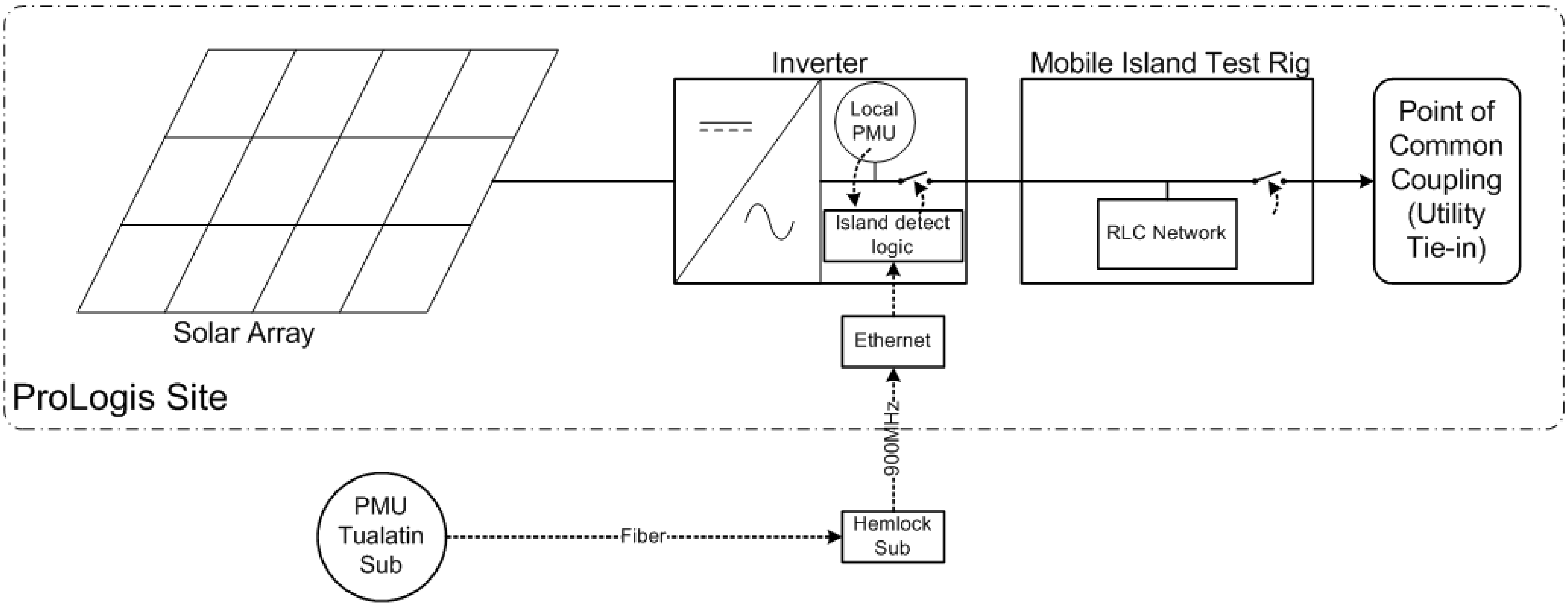
Wireless link

- Latency ~50mS
- Synchrophasor data packets transmitted at 20 hz
- System in inverter receives remote and local PMU data and performs CCB on it

Test Rig Tie-in and Inverter Under Test

Island Test Rig **Inverter** **Test Rig Tie-in**

Synchrophasor Island Detection



Island Demonstration Process Overview

1. Disable inverter-based island detection
2. Identify available power
3. Limit power output to enable island
4. Calculate tank circuit parameters
5. Setup tank circuit
6. Demonstrate island without any anti-islanding
7. Reconnect to grid
8. Enable synchrophasor island detection
9. Island
10. Validate disconnect and illustrate detect time
11. Repeat

PVP260kW Inverter

- *Integrated local PMU*
- *Integrated utility controls*
- *Integrated CCB island detection*

Agenda: Morning Presentations

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  - Michael Mills-Price, SEGIS Program Manager, AE Solar Energy
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  - Michael Mills-Price, SEGIS Program Manager, AE Solar Energy
- **12:15-1:15: Lunch**

Agenda: Afternoon Interactive Discussion and Live Demonstration: 2 Tracks

Red Track

1:15-3:00: Interactive Discussion at Embassy Suites

3:00-3:15: Break

3:15: Load bus to Demonstration Site

3:30: Bus departs hotel

3:45: Arrive at Prologis Demo Site

3:45 – 4:45: Live demonstration presentation

4:45: Load bus back to hotel

5:00: Arrive back at hotel

5:00 – 5:30: Conference Wrap and Refreshments

Blue Track

1:15: Load bus for Demonstration Site

1:30: Bus departs hotel

1:45: Arrive at Prologis Demo Site

1:45- 2:45: Live demonstration presentation

2:45: Load bus back to hotel

3:00: Arrive back at hotel

3:00-3:15: Break

3:15-5:00 Interactive Discussion at Embassy Suites

5:00 – 5:30: Conference Wrap and Refreshments

6:30 – 9:00 VIP EVENT: Buses ready to board at 6:15

Lunch Break

12:15 – 1:15

Agenda: Afternoon Interactive Discussion and Live Demonstration

Interactive Discussion

High Penetration PV Issues and Options on the Distribution Network Tucker Ruberti, Director of Commercial Product Management, AE Solar Energy (35 min)

Utility Interactive Controls – Theory and Practice– UIC implemented PG&E/CEI Todd Miklos, Sr. Director, Utility Inverter Marketing, MSEE

(35 min)

Q&A: 20 min

Live Demonstration

Safety Brief (5 min)

System Overview (5 min)

Tour the trailer and inverter area, electrical room (10 min)

Demonstration explanation (10 min)

Island (5 min)

3 island detection tests (15 min)

Q&A (10 min)

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High Penetration PV Issues & Options On the Distribution Network

Tucker Ruberti
Director of Commercial Inverters
AE Solar Energy

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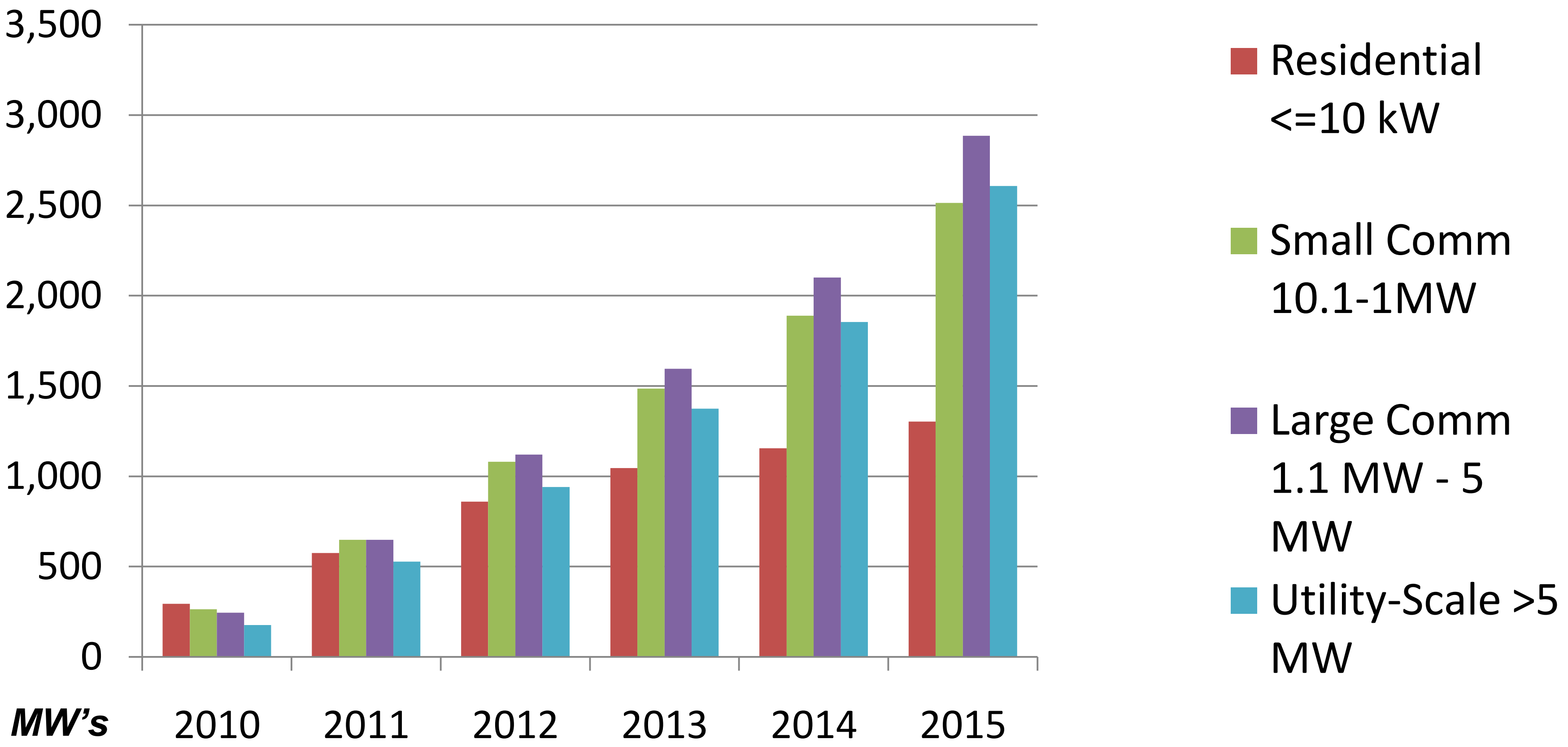
September 20, 2011

Agenda

- Is Distribution Level PV Big Enough to Matter to the Grid?
- What is High Penetration at the Distribution Level and When Will it Happen?
- What are the Effects of High Penetration PV on the Distribution System?
- How can the Effects be Mitigated?
- Selecting Appropriate Solutions to go from PV Mitigation to Active Grid Support

Which Segments Matter Most to the Grid?



*** Source- IMS**

All of them- each segment is becoming a multi-GW resource, but each needs to managed very differently

High Penetration “Sweet Spot”

The US has hundreds of GW of commercial rooftop potential that is being rapidly developed

1-5 MW rooftop is market an economic sweet spot- can it be a utility support sweet spot too?

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BUT, Rapid Growth is Not Assured

- Utilities have three core responsibilities
  - Safety
  - Reliability
  - Low Price
- The PV industry needs to prove to Utilities that high levels of distributed PV will not compromise their core mission
- Going beyond "do no harm" and proactively providing grid support will accelerate acceptance

This is the primary purpose of SEGIS!

What is High Penetration PV on the Distribution Level?

- Is it 5%, 10%, 20%, other?
- 5%,10% or 20% of what?
- What are other ways to define high penetration?

High Penetration is Defined by Effects

- PV is impacting utility distribution feeders today- reported problems, or concerns, include:
  - **Flicker-** Voltage changes that exceed IEEE-519 limits
  - **Voltage Rise-** PV can increase line voltage if installed far away from substation ands exporting power
  - **High Duty Cycles-** Capacitor banks and tap changers operate too often and fail early
  - **Reduced Power Factor-** If PV generates unity power factor, utility must provide a higher percentage of reactive power

When is Mitigation Required?

- Utilities are now conducting impact studies for systems <1MW and denying interconnects or requiring mitigation
  - Mitigation is required when the utility determines that the PV system may negatively affect their grid stability/performance
  - There are IEEE, Rule 21, and "rule of thumb" thresholds, but these only provide guidance on when a study may be required
- Examples of Concerns
  - CA Consultant- Modeled "variable" wind site and saw 32 tap changes per day, no capacitor switching. Modeled a "variable" PV site and saw 78 tap changes per day, and 5 cap bank changes.
  - GE (SPI 2010)- Modeled 20% PV penetration on the western grid. 1547 compliance caused grid to crash from Seattle to Mexico to Denver. PV needs its version of FERC order 661- except on the distribution system.

"External" Mitigation Options

- **Transfer Trip-** A disconnect at a distributed generation resource that is under utility control. Very expensive and binary. No options for intelligent controls.
- **DVAR/STATCOM-** Dynamic VAr Compensators and Static Compensators can provide grid support, but at a high cost.
- **Cap Banks-** New capacitor banks can also provide voltage regulation but are slow and expensive
- **Backfeed Protection Relays-** Devices that can assure that distributed generation does not feed power into the grid

Why Inverter-Based Solutions are Needed

- Distributed PV can't "scale" quickly by relying on costly external utility support equipment
- Inverters are inherently capably of providing all the functionality of external mitigation devices-
  - Many of the components are the same.
- The added benefit is that inverters are at the interface of the PV resource and the Grid
  - More "levers" to pull without complex interfaces between systems
  - High speed processor
  - Ability to synthesize waveform on demand

Grid Support Inverter Functions

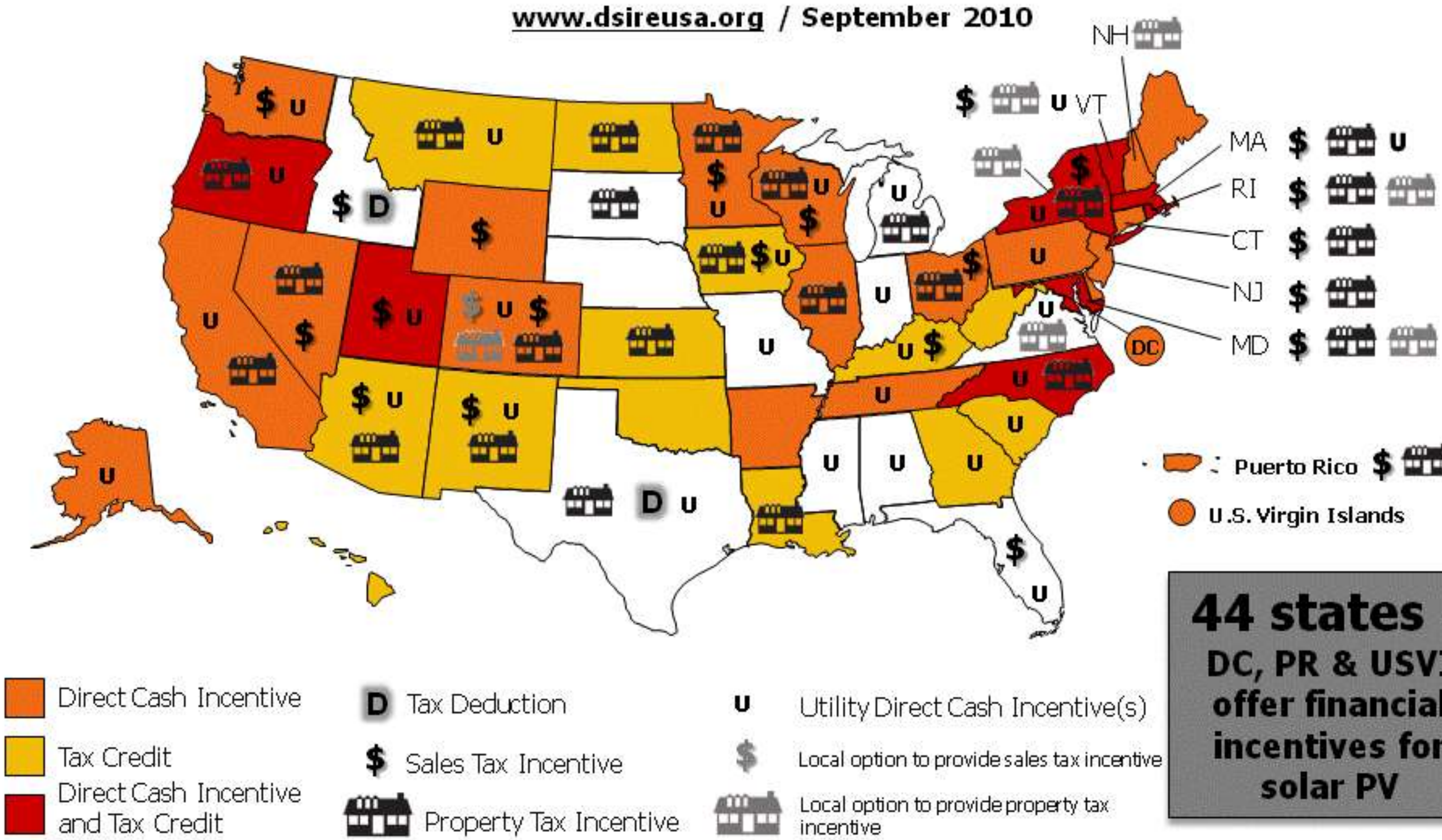
- Inverter features that comply with UL1741/IEEE1547:
  - Power factor/VAr control
  - Curtailment
  - Ramp rate control
  - Remote on/off

These are all part of new SPF Software Package

- Inverter features that **do not** comply with UL1741/IEEE1547 are:
  - Any active voltage regulation at the interconnection point
  - Voltage and frequency ride-through outside IEEE1547 limits

These are offered by AE at Utility Scale- Offering on the distribution level is still very complex and somewhat uncharted

PV's Challenge: 50 States & 3,000+ Utilities Creates Uncertainty & Complexity



44 states + DC, PR & USVI offer financial incentives for solar PV

Anti-Islanding: Key Barrier to Enable Most Important Grid Support

- Inverters are inherently capable of offering grid support
  - However, **safety** must be ensured when new features are implemented
- All PV inverters suppliers will offer grid support functions
  - Differentiating features will be reliability, cost, scalability and ease of use for utility coordination
- Without standardized interconnection rules solutions need to be cost efficient and flexible
- AE's selected path
  - utilize smart grid technologies that are already being deployed in high quantities to enable new future functions
  - keep incremental cost low per site

Anti-Islanding Alternatives

- Classic “Perturb and Observe” island detection schemes are incompatible with new needs such as low voltage ride through (LVRT)
- Three new solutions are being considered so far:
  - **Power Line Carrier (PLC)-** A signal carried over the power lines that indicates if the grid is still present
  - **Transfer Trip-** Traditional utility method to disconnect a generation source- requires a dedicated comm link and site specific engineering as well as costly hardware
  - **Synchrophasor-** comm link from substation to inverter that enables intelligent island detection and advanced functionality

Why Synchrophasors are Promising

- Phasor measurement units (PMU's) are widely deployed in substation gear across the US
  - SEL is actively seeding the market
- Scalable with small incremental costs
- Does not affect power quality
- Enables a robust set of responses and control strategies that are not possible with "binary" solutions like PLC or Txfr-Trip
  - Coordination with utility protection systems, demand management, voltage regulation, etc
  - Enables promise of PV <u>improving</u> grid performance

AE Portfolio of Utility Interactive Controls

Normal Mode

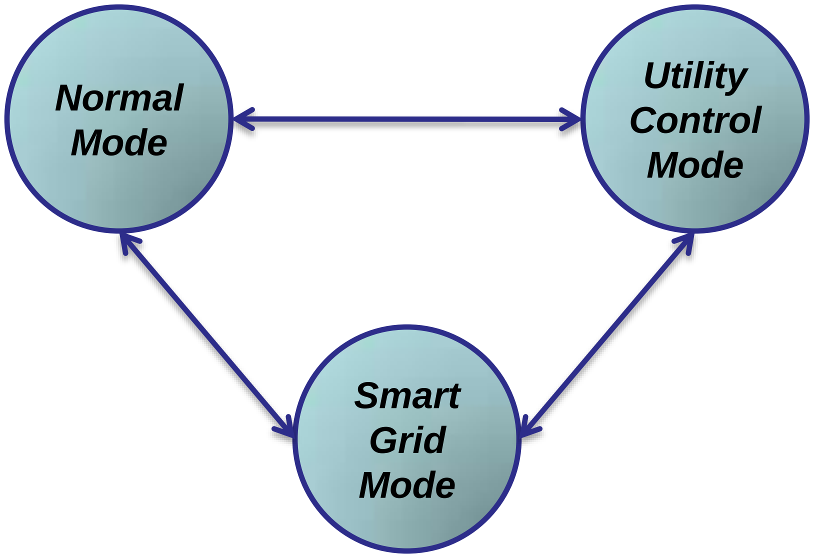
- IEEE 1547 Anti-islanding
- Traditional Resi, Commercial

Utility Control Mode

- SCADA compatible
- Interactive, Autonomous

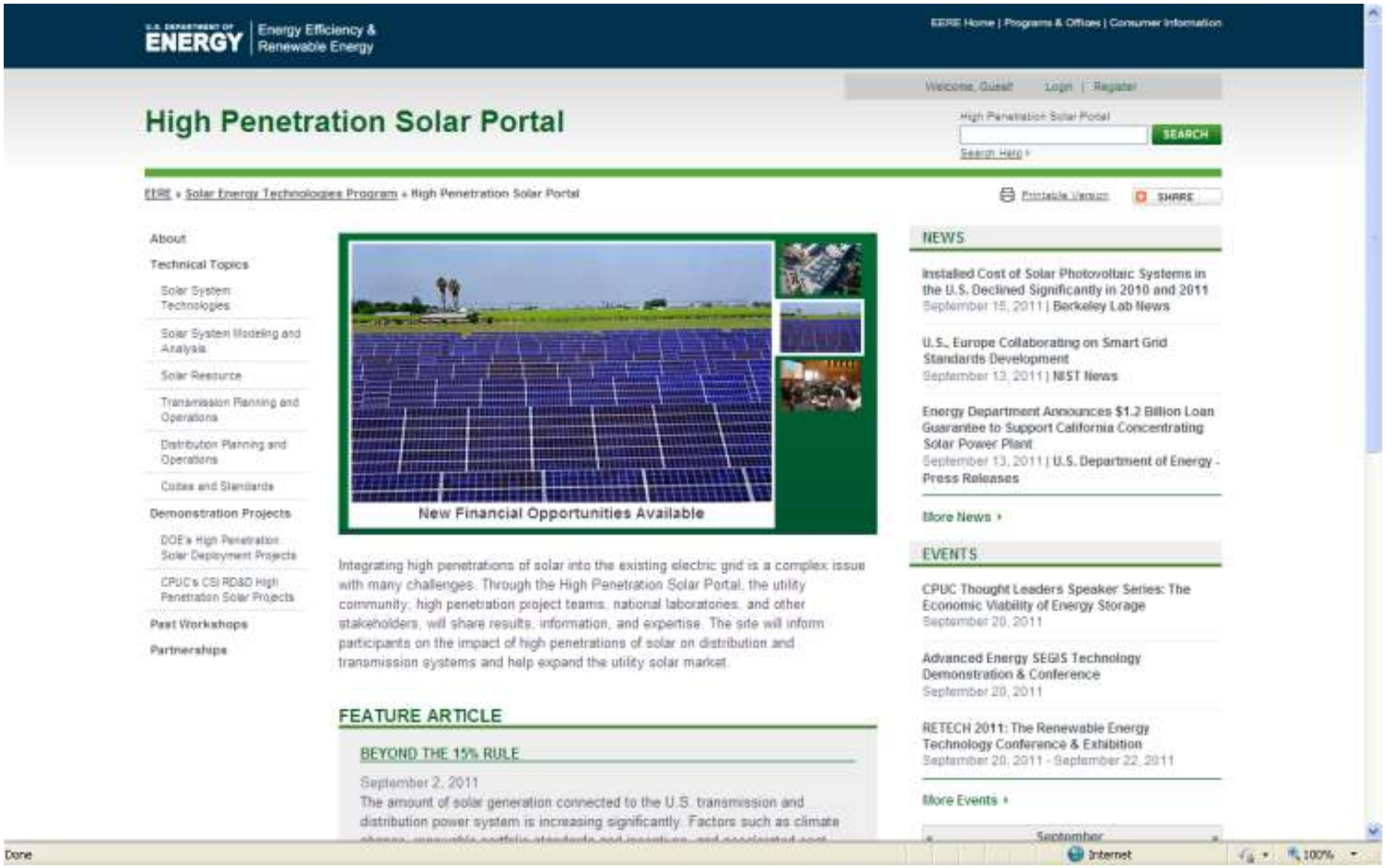
Smart Grid Mode

- Set and Forget
- Interactive, Autonomous, Scheduled



Spectrum of combinations and customization by site

High Penetration Resource- EERE/SETP Site



Loaded with insightful case studies, analysis, presentations, etc

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Take-Aways

- Clustering of PV installations has caused high penetration to arrive earlier than many expected
- Through SEGIS, Advanced Energy has partnered to develop and field-test a portfolio of solutions to address the full range of installation sizes and regulatory environments
- Advanced Energy is deploying inverter systems today that mitigate challenges of increased PV penetration
  - Developing short and long range solutions to industry challenges
  - Commercialization approach that enables choice

Utility Interactive Controls – Theory and Practice

Todd Miklos
Sr. Director, Utility Inverter Marketing, MSEE
AE Solar Energy

September 20, 2011

Topics

- Utility Interactive Controls
- UIC Details
  - kVARs
  - LVRT
  - Volt / VAR
- UIC in Practice – PG&E
  - Active Power %
- Summary

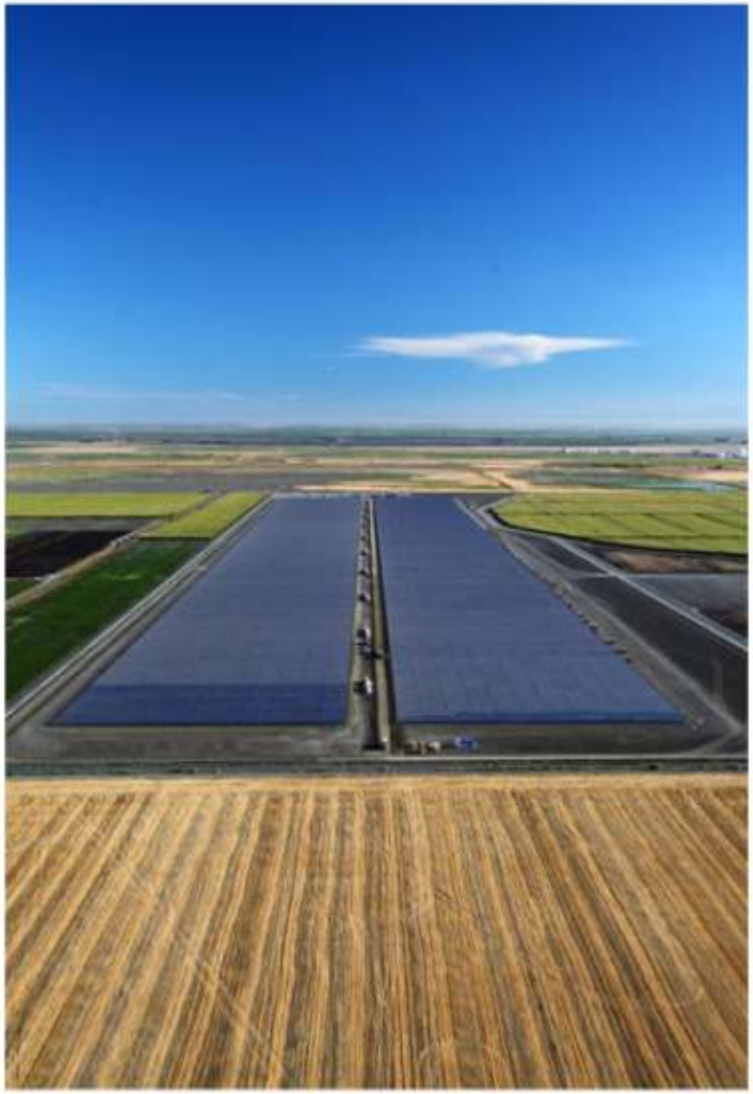


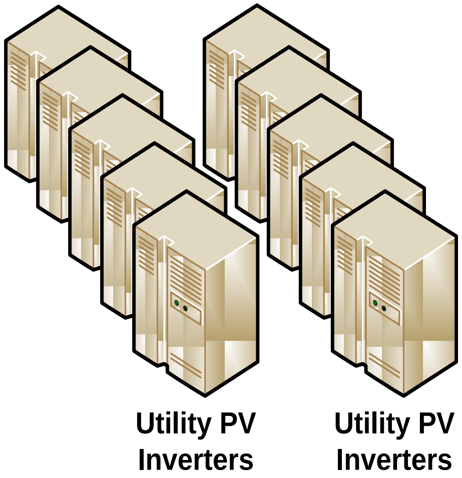
Image: courtesy of PG&E, CEI

AE Utility Interactive Controls

- ✓ Remote On/Off
- ✓ Reconnect Delay Control
- ✓ Active Power P Remote Set point (kW)
- ✓ Reactive Power Q Remote Set point (kVAR)

- ✓ Reconnect Ramp Rate Control
- ✓ Reactive Power Fixed Power Factor (Cos(φ))
- ✓ Ride-Through (LVRT, HVRT, ZVRT)
- ✓ Autonomous Frequency/Watt Control

- ❑ Autonomous Watt/VAR Control
- ❑ Autonomous Volt/VAR Control
- ❑ Scheduled Power Factor
- ❑ Synchrophasor Island Detection



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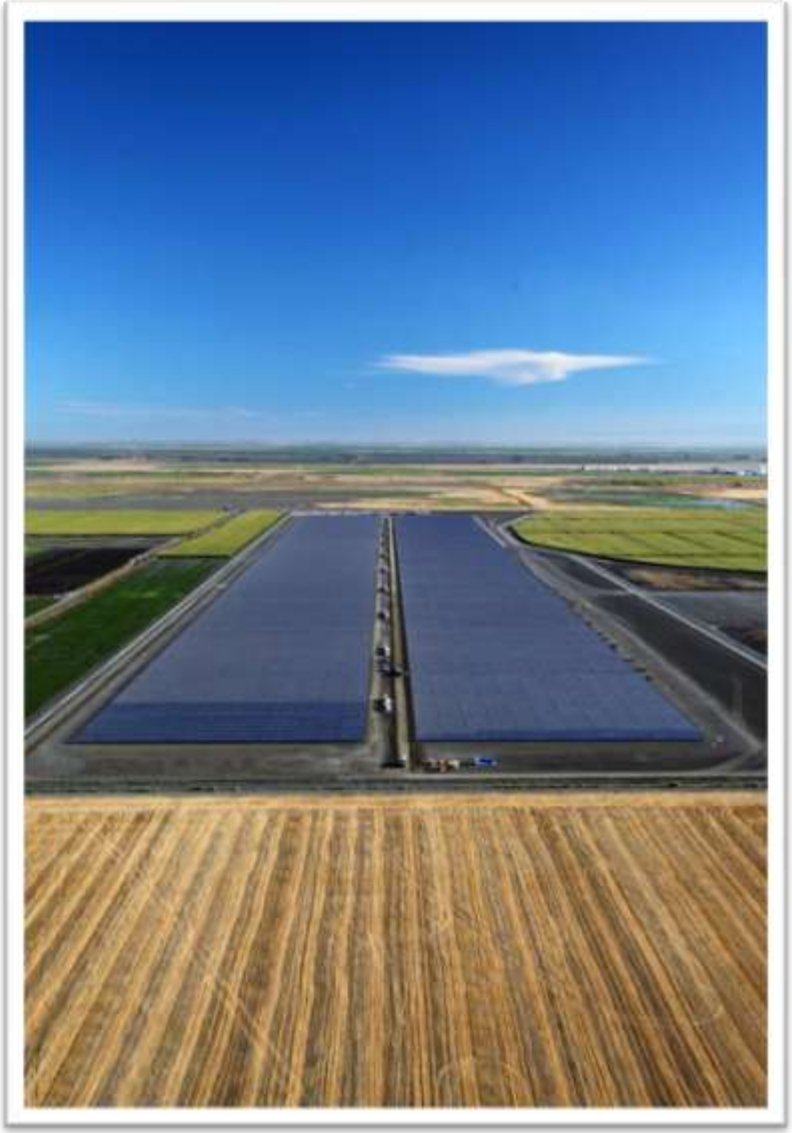
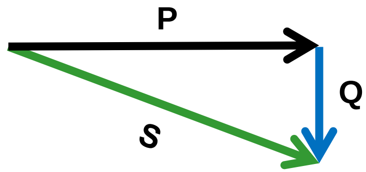


Image: courtesy of PG&E, CEI

kVAR Fundamentals

Basic principle: $\overrightarrow{\mathbf{S}}$ (kVA) = $\overrightarrow{\mathbf{P}}$ (kW) + $\overrightarrow{\mathbf{Q}}$ (kVAr)



Power factor describes “effectiveness” of AC electricity

- Power factor = 1.0 great!
- Power factor = 0.85 not so well
- Power factor < 0.95 might get higher bills

kVARs move power factor off 1.0, so must be managed

But kVARs are not all bad

- kVARs energize windings, enabling motors to run
- kVARs enable capacitive smoothing of harmonics
- kVARs are present in transformers, heaters, and other equipment

So, managing kVARs within a finite range is usually the goal

kVAR Benefits and Tradeoffs

Range of benefits:

- Improvement of LCOE through kVAR correction
- Compensation for line reactance to new solar plant
- Minor adjustments to local grid power factor
- Dynamic adjustment of power factor during the day
- Combinations of kW and kVAR for special situations

There's no such thing as a free kVAR lunch

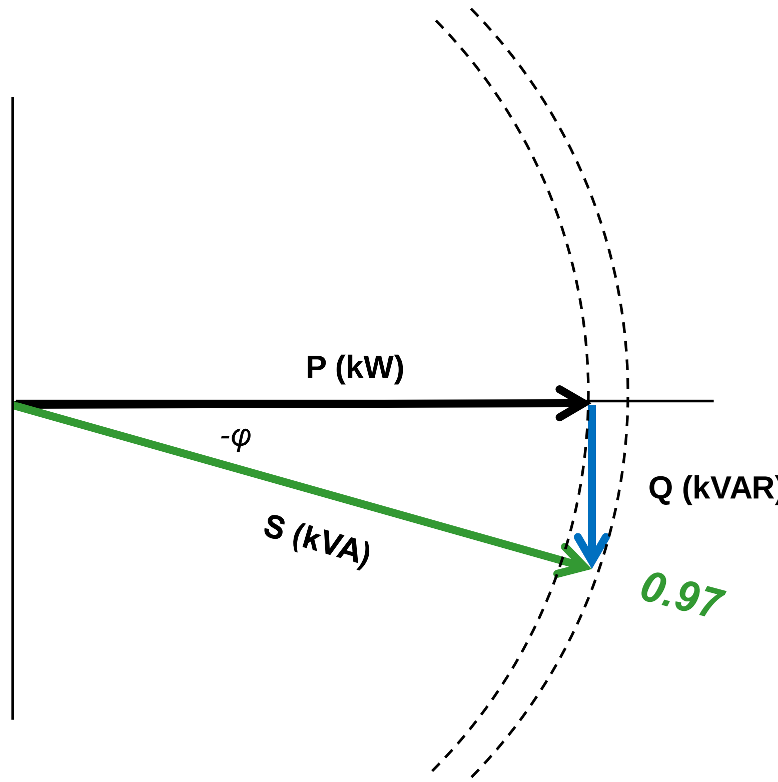
Solar inverters must be "oversized" to produce kVARs at full power

- Remember the power triangle
- kVA rating > kW rating
- If not, kW and kVAR will be traded off during operation
- Fixed power factor can manage a constant ratio over dynamic conditions

How Much Over-Sizing is Required?

Right triangle relates kW, kVAR, kVA, and power factor

- $kW^2 + kVAR^2 = kVA^2$
- Power factor = kW / kVA



Example:

- Goal is 500kW output with power factor of .97 sourcing
- kVA = kW / pf
  = 500kW / 0.97 = **515kVA**
- $kVAR = \text{sqrt}(kVA^2 - kW^2)$
  $= \sqrt{(515^2 - 500^2)}$ = **125 kVAR**

So in practice, 0.97 at full power requires 515kVA from a“500 kW” inverter

In Practice - Designing for kWs & kVARs

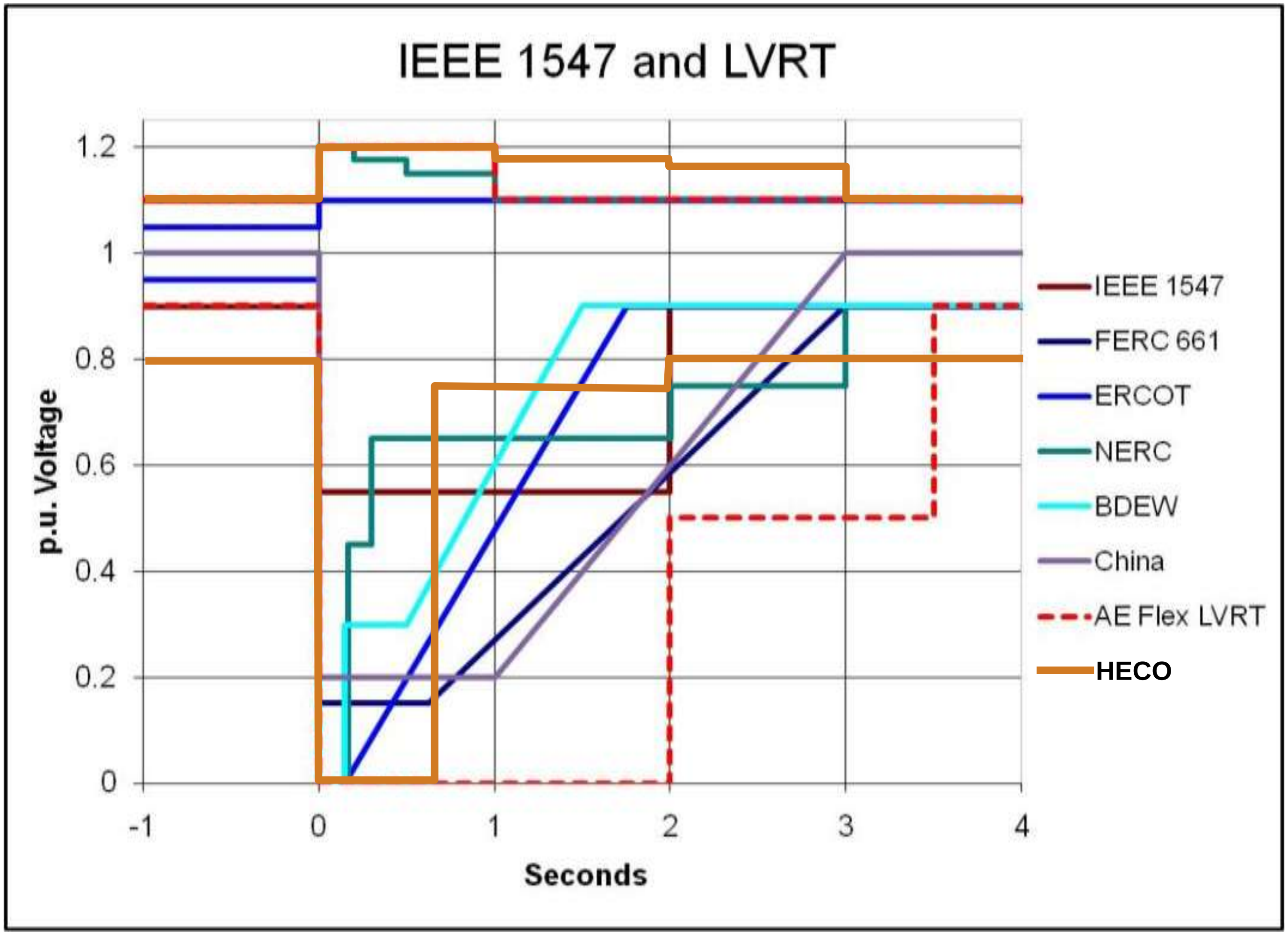
- Analyze needs on site by site basis

- Select intelligent solar inverter capable of both kW and kVA output
- Size array to provide total apparent power (kVA)
- Size wire and transformers appropriately

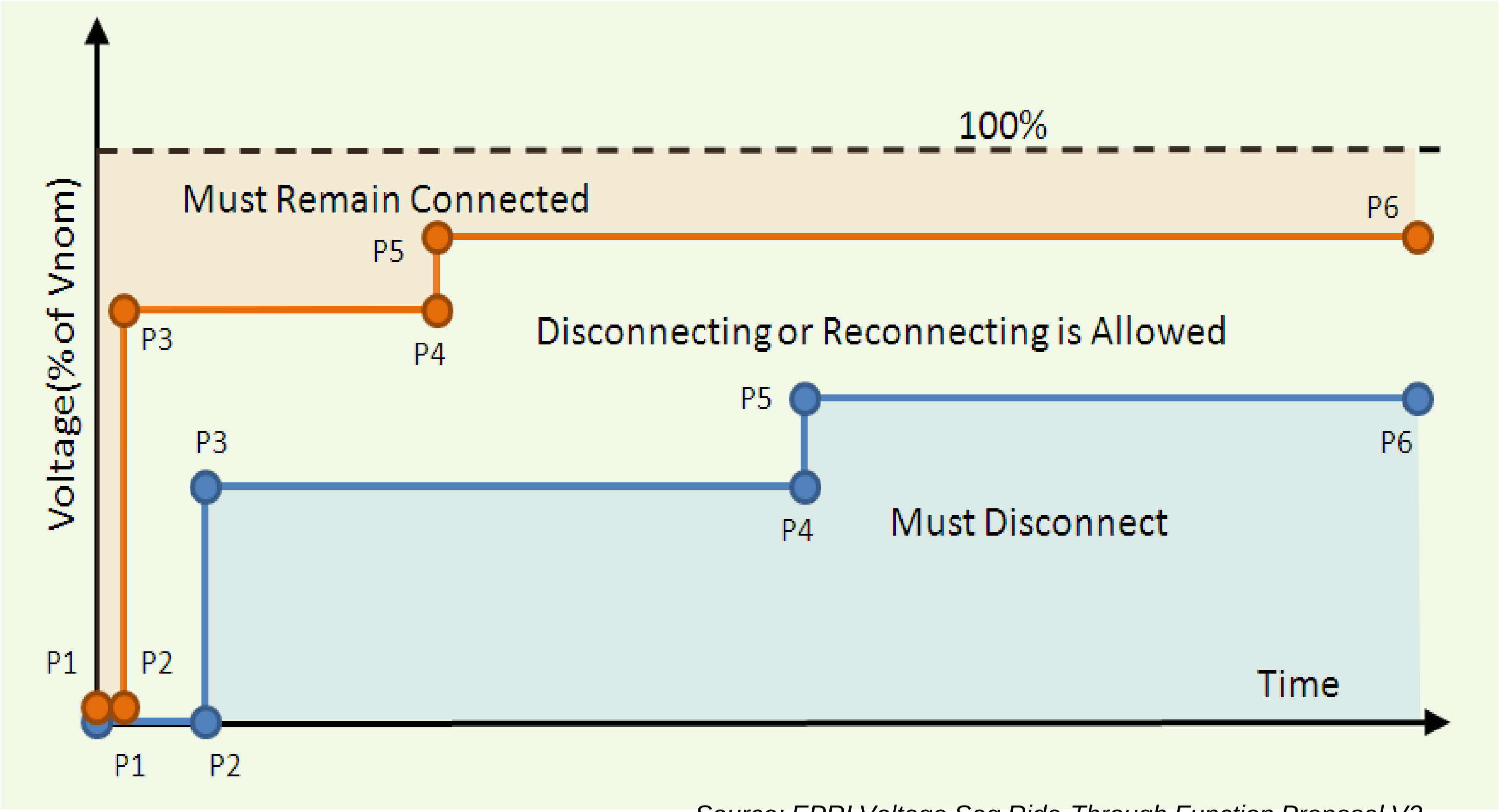
- Understand benefits and constraints of solar-based kVAR systems
- Model capabilities on DC side w/ stringing, weather, architecture
- Model AC through MV transformer onto grid

- Provide SCADA for monitoring and control of solar plant

LVRT - Which One?

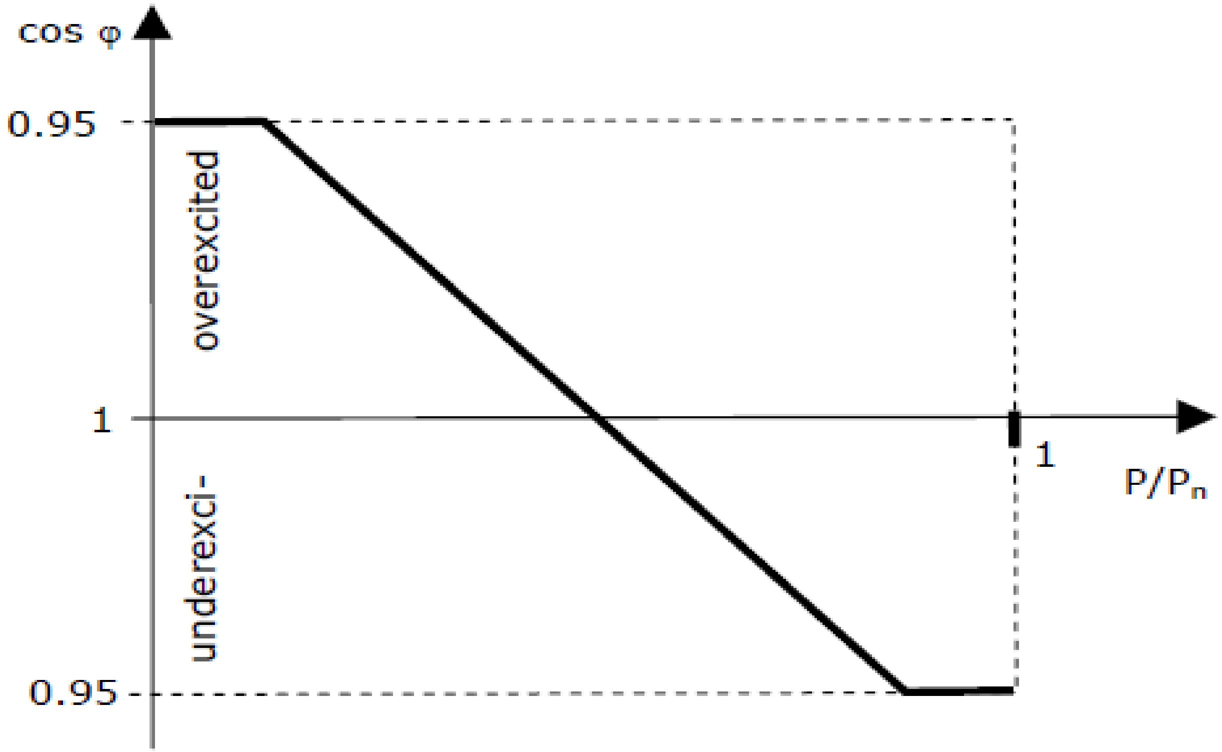


Practice – Tune EPRI "VSRT" w/ Deadbands



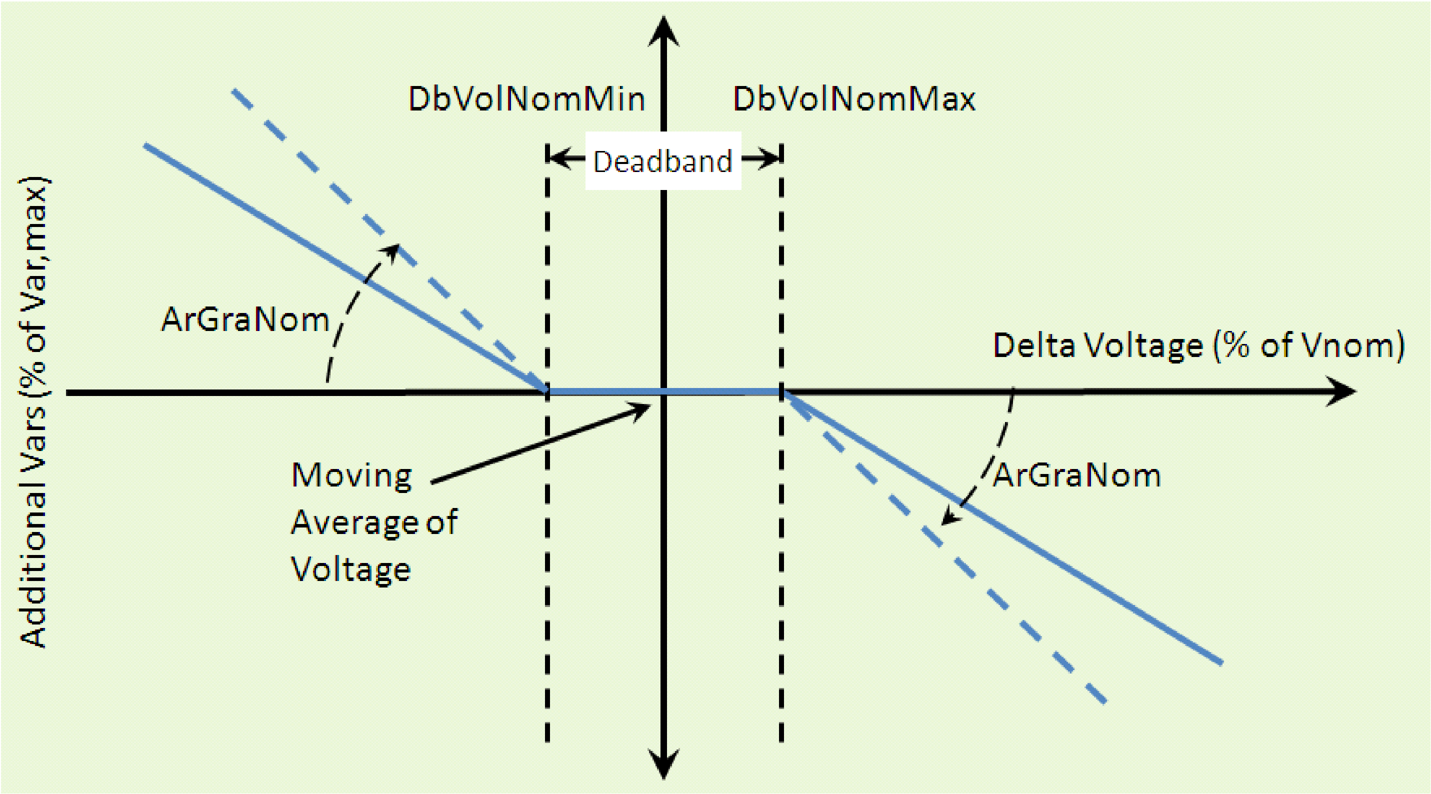
Source: EPRI Voltage Sag Ride-Through Function Proposal V2

Principle: Volt / VAR Dynamic Curve (BDEW)



Source: BDEW Generating Plants Connected to the Medium Voltage Network

Update: Volt / VAR Dynamic Curve (EPRI)



Source: EPRI Dynamic Volt-Var Function Proposal V2

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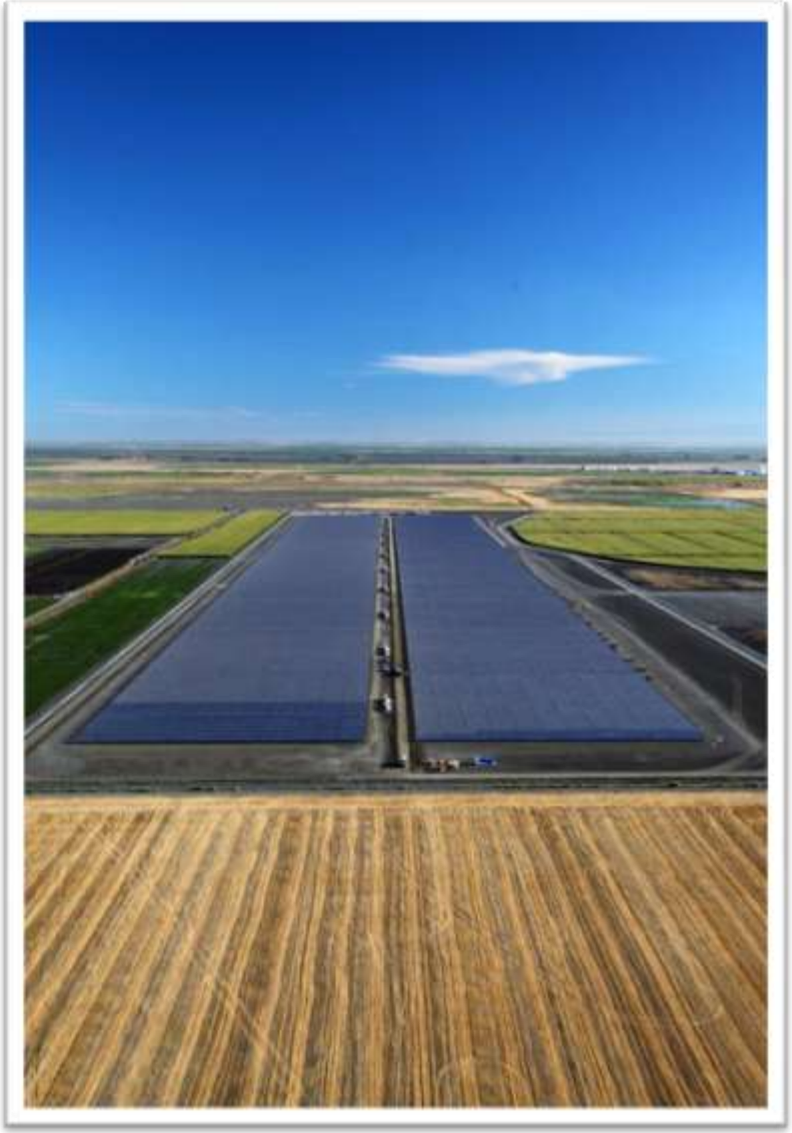

Image: courtesy of PG&E, CEI

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SCHWEITZER ENGINEERING LABORATORIES, INC.

Sandia National Laboratories

UIC In Practice – PG&E 35MW AC

SEL SCHWEITZER ENGINEERING LABORATORIES, INC.

Sandia National Laboratories

Available Utility Interactive Controls

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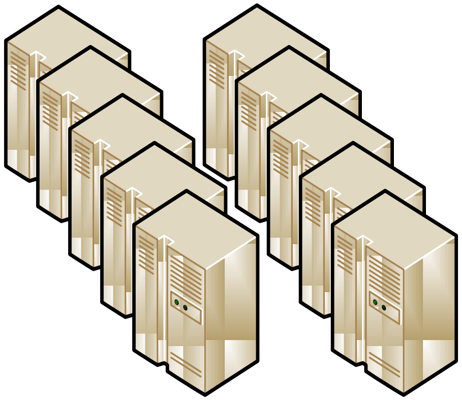

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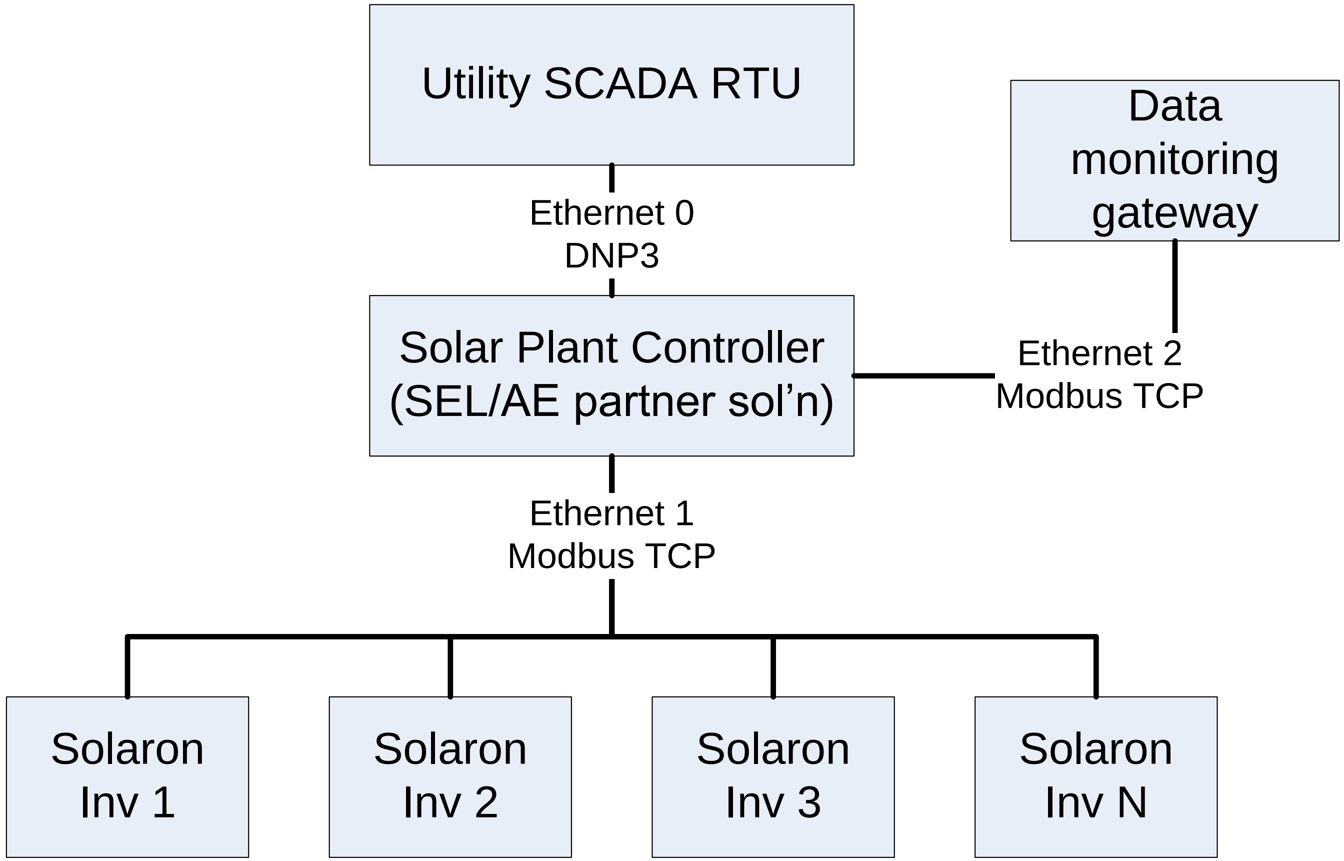
Implementation: Solar Plant Controller



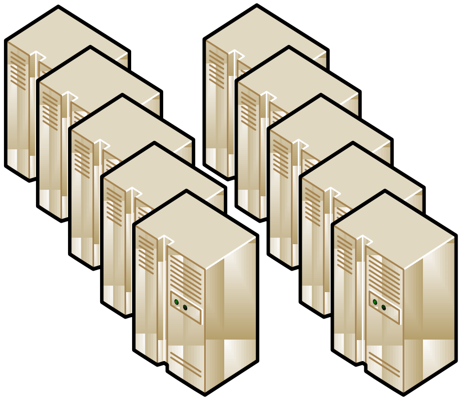
In Practice: Power Ramp

Situation: Dozens of inverters, ramping together

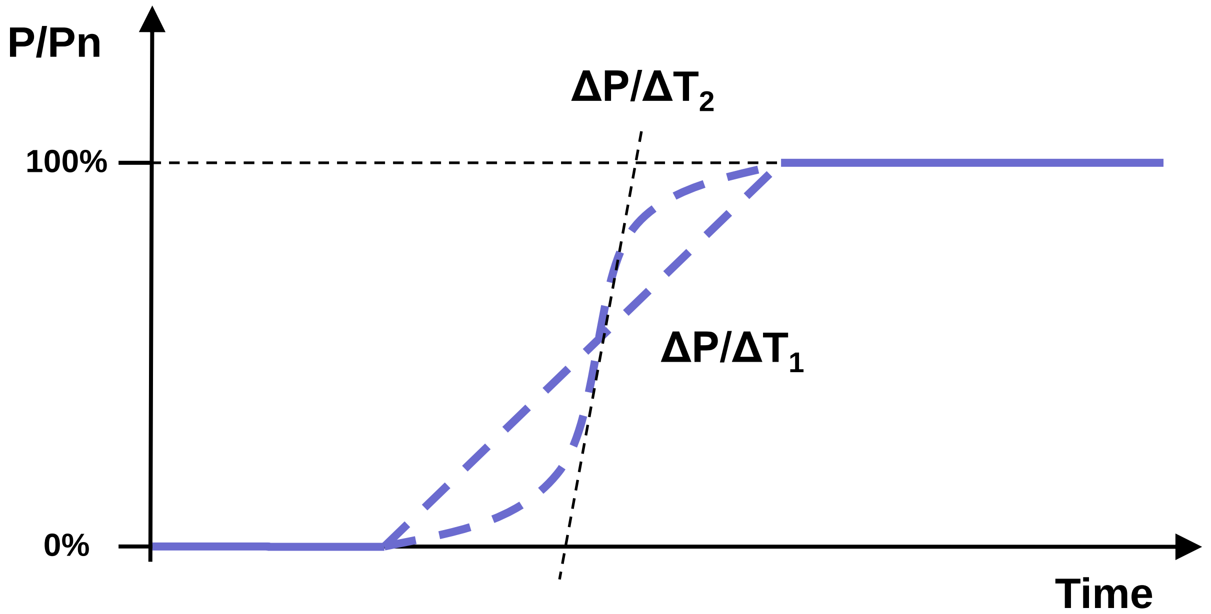
Consideration: How to ramp from 0% to 100% power?

Possible approaches:

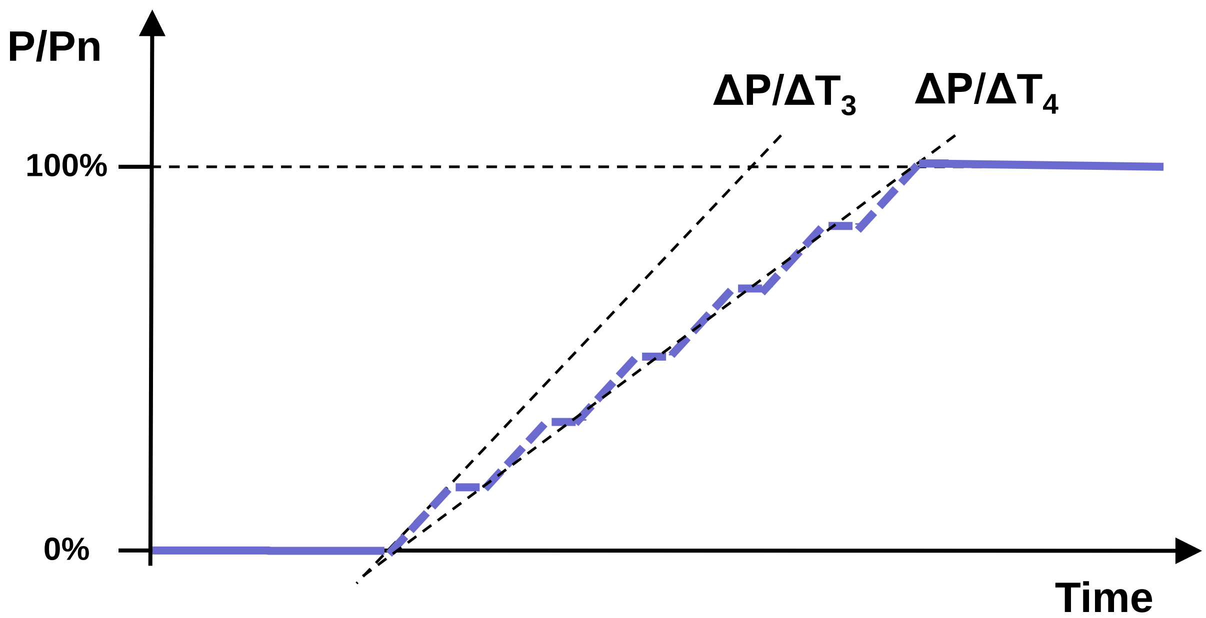
- Independent “best effort”
- Synchronized linear ramp
- Sequential time-shifted ramp
- Other


Utility PV Inverters

Active Power Set-Point and Ramp Rate: Linear Ideal vs. Independent Ramp



Active Power Set-Point and Ramp Rate: Sequential Ramp



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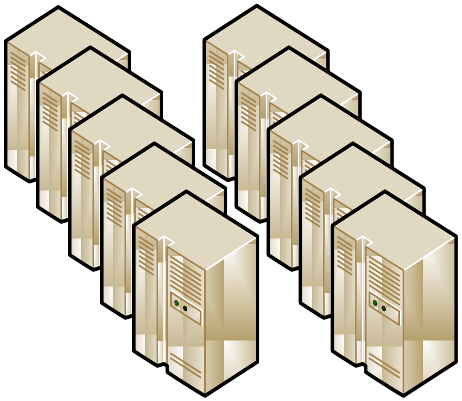


Utility PV Inverters

Approach at PG&E Westside:

- Sequential ramp via Reconnect Delay setting on each inverter
- Each 1MW station (x2 inverters) comes up each minute for 20 minutes

Solaron® Inverters at Work

Thumbs Up! Solar PV Plant Online, Under Control of FOC, 40 Miles Away

AE Portfolio of Utility Interactive Controls

Normal Mode

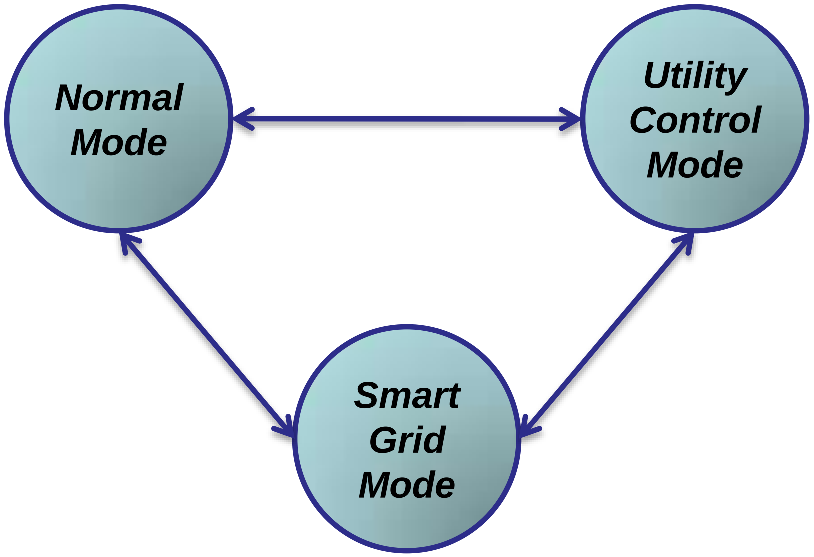
- IEEE 1547 Anti-islanding
- Traditional Resi, Commercial

Utility Control Mode

- SCADA compatible
- Interactive, Autonomous

Smart Grid Mode

- Set and Forget
- Interactive, Autonomous, Scheduled



Spectrum of combinations and customization by site

NASDAQ: AEIS

www.advanced-energy.com

Agenda: Afternoon Interactive Discussion and Live Demonstration: 2 Tracks

Red Track

1:15-3:00: Interactive Discussion at Embassy Suites

3:00-3:15: Break

3:15: Load bus to Demonstration Site

3:30: Bus departs hotel

3:45: Arrive at Prologis Demo Site

3:45 – 4:45: Live demonstration presentation

4:45: Load bus back to hotel

5:00: Arrive back at hotel

5:00 – 5:30: Conference Wrap and Refreshments

Blue Track

1:15: Load bus for Demonstration Site

1:30: Bus departs hotel

1:45: Arrive at Prologis Demo Site

1:45- 2:45: Live demonstration presentation

2:45: Load bus back to hotel

3:00: Arrive back at hotel

3:00-3:15: Break

3:15-5:00 Interactive Discussion at Embassy Suites

5:00 – 5:30: Conference Wrap and Refreshments

6:30 – 9: VIP EVENT: Buses ready to board at 6:15

Questions/Comments

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